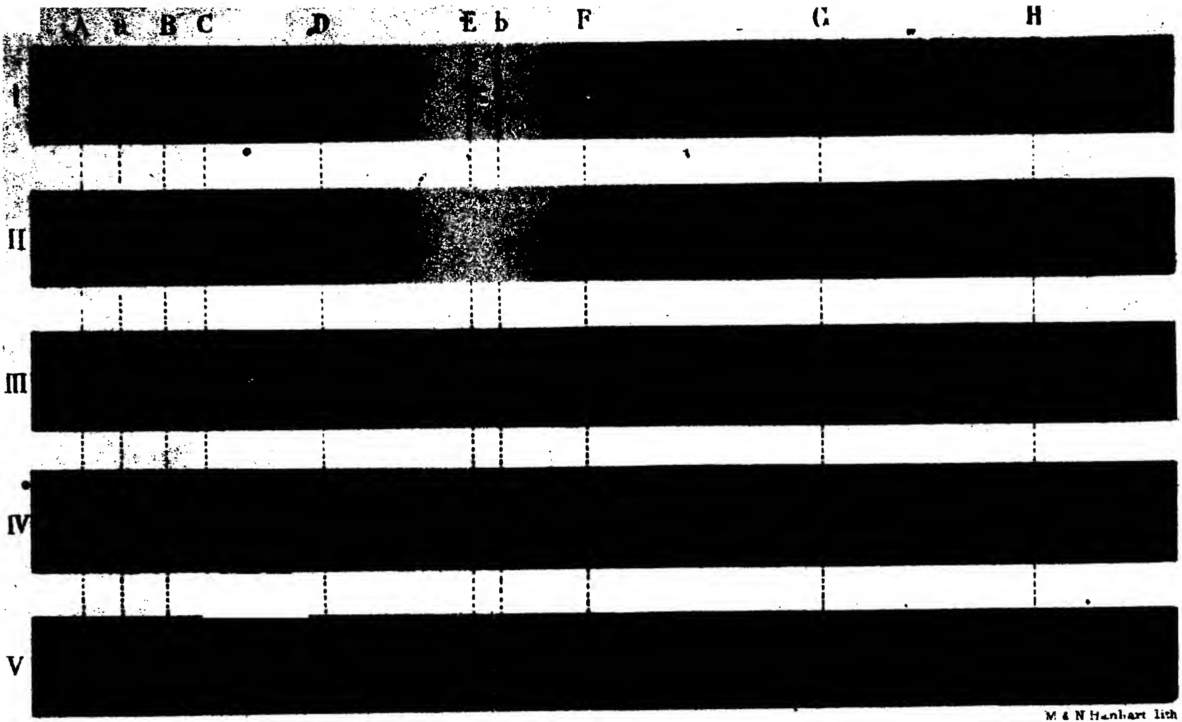
NATURAL PHILOSOPHY.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NATURAL PHILOSOPHY

FOR

GENERAL READERS AND YOUNG PERSONS.

TRANSLATED AND EDITED FROM

GANOT'S COURS ÉLÉMENTAIRE DE PHYSIQUE

(*with the Author's sanction*)

BY

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PREFACE.

THE present work has its origin in an attempt to comply with a suggestion which has frequently been made to me, that I should prepare an abridged edition of my translation of Ganot's *Éléments de Physique*, which could be used for purposes of more elementary instruction than that work, and in which the use of mathematical formulæ would be dispensed with. But I soon found that to do anything of the kind which would be more than a mere series of extracts would be very difficult, and hence I turned my attention to another book by the same author, which has had a very extensive circulation in France, his *Cours élémentaire de Physique*, and this I have taken as the basis of the present book.

It is not a mere translation, but such additions and alterations have been made as I thought fitted to render the book useful to the classes for which it was more especially

designed—namely, as a text-book of physics for the middle and upper classes of boys' and of girls' schools, and as a familiar account of physical phenomena and laws for the general reader. In range it may perhaps be fairly taken to represent the amount of knowledge required for the matriculation examination of the London University.

Although English scientific literature is not wanting in works in which the main physical phenomena are explained in familiar language, they are for the most part—whether from too much conciseness in some parts or from too minute details in others, or again as being too costly—not suited for direct teaching purposes.

To facilitate reference, the articles of the present work have been numbered, and a copious index has been drawn up in accordance with this arrangement.

E. A.

STAFF COLLEGE:
May, 1872.

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Errata

Page 17, line 5 from bottom, *for* that *read* the intensity of
,, 29, ,, 20 from bottom, *for* in like manner one *read* in like manner if one
,, 30, ,, 1, *for* second *read* first
,, ,, ,, 2, *for* first *read* second
,, ,, ,, 11 from bottom, *for* may assume *read* may be assumed
,, 44, lines 2 and 3 from bottom, *for* gravitation *read* gravity (vide Art. 36).
,, 54, line 16 from bottom, *for* axis *read* rod
,, 57, ,, 13 from bottom, *for* gravitation *read* gravity
,, 81, ,, 9 from bottom, *omit* geographical
,, 152, ,, 7 from top, *for* heard *read* produced
,, 211, ,, 19 from top, *for* value of the expansion *read* value of the coefficient of expansion
,, 242, ,, 8 from bottom, *for* following *read* foregoing
,, 281, ,, 11 from bottom, *for* emit *read* transmit
,, ,, ,, 8 from bottom, *for* translucid *read* translucent
,, 442, ,, 8 from top, *for* Fig. 336 *read* Fig. 346; and omit letters of reference in the text
,, 443, ,, 11 from bottom, *for* Identity of thunder and lightning *read* Thunder and lightning the effect of electricity
,, 494, last line, omit x

ELEMENTARY COURSE

OF

PHYSICS

BOOK I.

GENERAL PROPERTIES OF MATTER, AND UNIVERSAL ATTRACTION.

CHAPTER I.

PRELIMINARY NOTIONS.

1. **Definition of physics.**—The word *physics* is derived from the Greek, φύσις, nature, for the ancients understood by the term physics the study of the whole of nature. They comprised within the domain of this science *mechanics*, *astronomy*, *chemistry*, *botany*, *zoology*, *medicine*, and even *astrology* and *divination*, whether by the stars or by the observation of physiognomy.

The province of physics is at present much more restricted. Its object may be considered to be *the study of those phenomena which do not depend on changes in the composition of bodies; these belong to chemistry.*

Thus, when water by cooling is changed into ice, and by heat this ice is again changed into water, the liquid is exactly the same as before ; not merely are all its properties the same, but its substance is identical with what it originally was. The passage of water to the state of ice, and the return of the latter to the liquid state, are *physical phenomena.* In like manner, when a brittle object, of porcelain or glass, for instance, falls to the ground and breaks, each piece retains exactly the same chemical composition. The fall of the vessel and its fracture against the ground are then physical phenomena.

On the other hand, when wood burns, its substance is profoundly

modified. It consists of several different forms of matter, and is decomposed; one part of its elements passes into the atmosphere as smoke, while another is left as a residue consisting of ash and charcoal. In short, the substance we know as wood has disappeared, and is replaced by others which are entirely different. The combustion of wood is then a *chemical phenomenon.*

2. **Matter, mass, density.**—We understand by the term *matter* whatever can affect one or more of our senses; that is to say, anything whose existence can be recognised by the sight, touch, taste, smell, or hearing.

The *mass* of a body is the quantity of matter contained in this body. Different substances may contain very different quantities of matter in the same volume. It will subsequently be shown, for instance, that for equal volumes lead contains nearly eleven times as much matter as water, and gold nineteen times as much. This is expressed by saying that the masses of lead and of gold are respectively eleven and nineteen times as *dense* as water. When one body has for the same volume twice or thrice the mass of another, it is said to be twice or thrice as dense; and the *density* of one substance in reference to another is the number which expresses how much matter the first body contains as compared with the second.

3. **Simple and compound substances.**—It has been ascertained that all the various forms of matter with which we are acquainted may be resolved into about sixty-five different kinds, which are called *simple substances* or *elements*, to express that each only contains one kind of matter. Many of these are very rare, and are found in very minute quantities; others are more widely diffused, and have important uses, but are not abundant; and the great mass of the universe is made up of about fourteen: the *non-metallic bodies*, or *metalloids*, oxygen, hydrogen, nitrogen, silicon, carbon, sulphur, phosphorus, and chlorine; and the *metals* aluminum, potassium, sodium, calcium, magnesium, and iron.

Very few of these elements occur in nature in the free state; by far the greater number of the substances we know are *compound*, that is, formed by the union of two, three, or four of these elements. Thus water consists of hydrogen and oxygen; marble, of carbon, oxygen, and calcium; muscular tissue, of carbon, hydrogen, oxygen, and nitrogen. The number of substances containing more than four elements is very small.

The force in virtue of which different substances unite to form compounds, and which opposes the resolution of compounds into their elements, is called the force of *chemical attraction* or *affinity*

4. **Internal constitution of bodies, atoms, molecules, molecular forces.**—The properties of bodies prove that they are not formed of continuous and compact matter as they seem to be, but that they are agglomerations of excessively small material particles, which are called *atoms*. The elementary atoms can unite with each other to form compounds, but cannot be destroyed by any known process.

The term *molecule* is given to the smallest cluster of atoms of any substance which is conceived capable of existing by itself; every pure substance consists of similar molecules.

The same properties which have led physicists to assume the existence of atoms and molecules, have also led to the assumption that these small particles do not touch, but are simply juxtaposed, retaining between them excessively small intervals, which we shall afterwards investigate under the name of *pores* (9).

But it may be asked, How is it that bodies do not spontaneously fall into powder? What gives them solidity and hardness? What is the invisible force that unites atoms and molecules?

This force is the reciprocal attraction which the molecules of bodies exert upon each other and which is continually drawing them together. The force which holds together particles of the same kind of matter is called *molecular attraction*; the force which holds together particles of different kinds of matter is called *chemical attraction or affinity*. When hydrogen and oxygen unite to form water they do so by reason of the exercise of the latter force, while the particles of water are held together by molecular attraction.

If molecular attraction were the only force acting upon the small particles of which bodies are composed, they would come into complete contact, which is never the case. They are also under the influence of a repulsive force, in virtue of which their particles continually tend to separate themselves; this is the force of *heat*. Experiment shows, in fact, that whenever a body is heated its volume increases because its molecules are driven apart; while on the contrary its volume diminishes when it is cooled, because the molecules then become closer. The particular form which matter assumes—whether solid, liquid, or gaseous—depends on the extent to which it is influenced by these antagonistic forces.

5. **Different states of matter.**—All different substances present characters in virtue of which they may be divided into three distinct classes, *solids*, *liquids*, and *gases*.

Solids, such as wood, stones, metals, &c., are substances which

are more or less hard, and retain the form which they possess naturally, or which has been given them by art. It is assumed that in solids molecular attraction preponderates over repulsion.

Liquids, such as water, oil, mercury, are bodies which have no hardness, and present but little resistance when a body is immersed in them ; they have no shape of their own, but at once take that of the vessels in which they are contained ; they are virtually incompressible. We assume that in them molecular attraction is balanced by the repulsive force of heat, and that while the molecules can freely glide over each other they keep an invariable distance apart if the temperature be not altered.

Gases, such as hydrogen, oxygen, carbonic acid are also called *aeriform fluids* from their analogy with our air, which is a mixture of oxygen and nitrogen. They are very light bodies ; excepting a small number, which are coloured, they are invisible, and hence a vessel filled with air, hydrogen, or any colourless gas, appears quite empty. Like liquids, they have no shape of their own, but, unlike liquids, they are eminently compressible and expansible. In them the repulsive force of heat preponderates over molecular attraction (4) ; whence it follows that they are continually tending to occupy a larger space. This property will be described as the *expansibility* of gases (110).

There are many bodies which can exist in these three different forms; thus water, exposed to great cold, becomes solid in the form of ice; at ordinary temperatures it is liquid, while at higher temperatures it becomes a gas. Sulphur, iodine, and several metals present the same phenomena.

CHAPTER II.

GENERAL PROPERTIES OF BODIES.

6. **Extension.**—By *general properties* we understand those which are common to all bodies, whether solids, liquids, or gases ; such for instance are *extension*, *impenetrability*, *divisibility*, *porosity*, *compressibility*, *elasticity*, *inertia*, and *gravity*.

Specific properties are such as we observe only in certain bodies, or in certain states of those bodies ; solidity, fluidity, tenacity, malleability, colour, hardness, etc. are properties of this class.

The first general property of bodies with which we are concerned

is their *extension* or *magnitude*; that is, the extent of space they occupy. All bodies, even the smallest atoms, have a certain extension.

Extension considered in only one direction, that of length, gives a *line*; in two directions, length and breadth, a *surface*; and, in the three directions, length, breadth, and thickness, a *volume.*

With respect to the above general properties, it may be remarked that *impenetrability* and *extension* might be more aptly termed essential attributes of matter, since they suffice to define it; and that divisibility, porosity, compressibility, and elasticity do not apply to atoms, but only to bodies or aggregates of atoms.

7. **Impenetrability.**—This is the property in virtue of which two portions of matter cannot simultaneously occupy the same portion of space. Strictly speaking, this property only applies to the atoms of bodies.

In many phenomena bodies appear to penetrate each other. Thus, if a pint of water and a pint of alcohol be mixed, the volume of the mixture is less than two pints. A similar contraction occurs in the formation of certain alloys: thus brass, which is an alloy of copper and zinc, occupies a less volume than the united volumes of its constituents.

This penetration is, however, only apparent, and is due to an alteration in the position of the molecules; they come nearer each other, and the space occupied by the pores is diminished.

A nail driven into wood is not a case of penetration. The molecules of the latter are driven apart by the nail, but wherever it has penetrated there is no wood. When water has been poured upon a heap of sand it at once disappears; the water, however, does not penetrate the substance of the sand itself, but merely fills the interstices between the grains.

8. **Divisibility.**—This is the property which all bodies have of being divided into distinct parts.

Numerous examples may be cited of the extreme divisibility of matter. The tenth part of a grain of musk will continue for years to fill a room with its odoriferous particles, and at the end of that time will scarcely be diminished in weight.

Blood is composed of red, flattened globules floating in a colourless liquid called serum. In man the diameter of one of these globules is less than the 3,500th part of an inch, and the drop of blood which might be suspended from the point of a needle would contain about a million of globules.

Again, the microscope has disclosed to us the existence of insects smaller even than these particles of blood; the struggle for existence reaches even to these little creatures, for they devour still smaller ones. If blood runs in the veins of these devoured ones, how infinitesimal must be the magnitude of its component globules?

Has then the divisibility of matter no limit? Although experiment fails to determine such limit, many facts in chemistry, such as the invariability in the relative weights of the elements which combine with each other, would lead us to believe that a limit does exist. It is on this account that bodies are conceived to be composed of extremely minute and indivisible parts called *atoms* (4).

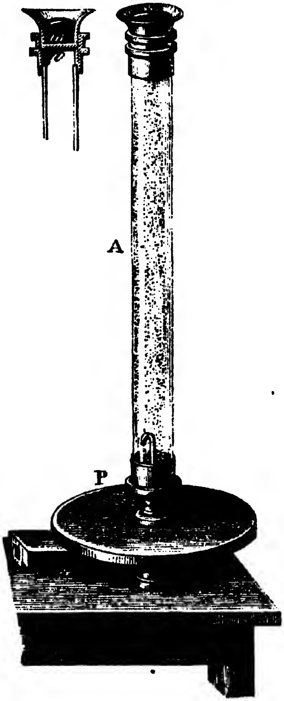


Fig. 1.

9. **Porosity.** — *Pores* are the extremely small intervals which exist between the molecules of bodies, and *porosity* is the property which bodies possess of having pores.

Two kinds of pores may be distinguished: *physical* or *intermolecular* pores, where the interstices are so small that the molecules remain within the sphere of each other's attracting or repelling forces; and *sensible* pores, or actual cavities, across which these molecular forces cannot act.

The contractions and dilatations resulting from variations of temperature are due to the existence of physical pores; whilst in the organic world the sensible pores are the seat of the phenomena of exhalation and absorption.

In wood, sponge, pumice stone, and in animal and vegetable tissues, the sensible pores are apparent; physical pores never are. Yet, since the volume of every body may be diminished, we conclude that all possess physical pores.

The existence of sensible pores may be shown by the following

experiment:—A long glass tube, A (fig. 1), is provided with a brass cup, *m*, at the top, and a brass foot made to screw on to the plate of an air-pump. The bottom of the cup consists of a thick piece of leather. After pouring mercury into the cup so as entirely to cover the leather, the air-pump is put in action, and a partial vacuum produced within the tube. By so doing a shower of mercury is at once produced within the tube, for the atmospheric pressure on the mercury forces that liquid through the pores of the leather. In the same manner water or mercury may be forced through the pores of wood, by replacing the leather in the above experiment by a disc of wood cut perpendicular to the fibres.

When a piece of chalk is thrown into water air-bubbles at once rise to the surface, in consequence of the air in the pores of the chalk being expelled by the water. The chalk will be found to be heavier after immersion than it was before, and from the increase of its weight the volume of its pores may be easily determined.

The porosity of gold was demonstrated by the celebrated Florentine experiment made in 1661. Some academicians at Florence, wishing to try whether water was compressible, filled a thin globe of gold with that liquid, and, after carefully closing the orifice hermetically, they exposed the globe to pressure with a view of altering its form, well knowing that any alteration in form must be accompanied by a diminution in volume. The consequence was, that the water forced its way through the pores of the gold, and stood on the outside of the globe like dew. This experiment has since been repeated with globes of other metals, and like results obtained.

The Florentine academicians had concluded from their experiments that liquids were incompressible; that is, could not be reduced in volume by pressure. This, however, is not the case, liquids are compressible, though to a very small extent. By cooling, the diminution in volume is far more considerable.

From these facts we conclude that the molecules of liquids may be brought nearer each other, and therefore that there are pores between them. The facility, moreover, with which liquids mix is a proof of their porosity.

10. **Applications of porosity.**—The property of porosity is frequently utilised, more especially in the process of *filtration*. This consists in clarifying liquids by freeing them from particles of matter which they hold in suspension; as is done, for instance, with

river water, which is turbid owing to the earthy matter it carries along with it.

The apparatus used for this purpose are called *filters*, and are usually constructed of unsized paper, felt, charcoal, etc. The pores of these substances are sufficiently large to allow liquids to pass, but small enough to arrest the particles held in suspension. Figure 2 represents a *filtering fountain*, one side of which is sup-

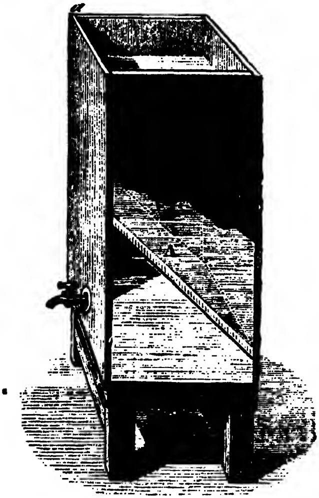


Fig. 2.

Fig. 3.

posed to have been removed, so that its construction is visible. It consists of a box about a yard high divided in the inside into two compartments by a porous stone, A. The water to be filtered is placed in the upper compartment, whence it slowly percolates through the pores of the stone into the lower one, leaving behind it the foreign substances. In one of the sides of the box is a tube *a*, which terminates in the lower compartment, and allows the air to escape in proportion as water enters.

Figure 3 represents a filter known as the *strainer of Hippocrates*. It is a conical felt bag suspended by three cords, into which is poured the turbid liquor; it slowly traverses the pores, while all the solid particles to which the turbidity is due remain behind on the filter. This method is well-adapted for clarifying syrups, jellies, and liqueurs.

Layers of powdered wood charcoal are also used for filtration. A layer of sand or of broken glass produces the same effect. The limpidity of well-water is due to the filtration through strata of earth.

11. **Compressibility.**—This is the property which bodies possess of being diminished in volume by pressure without undergoing any loss of weight. Being due to the approach of the molecules, it is both a consequence and a proof of porosity.

Compressibility is very marked in sponge, caoutchouc, cork, pith, paper, cloth, etc. Their volume is considerably diminished by mere pressure between the fingers. The compressibility of metals is proved by the impression which they receive from the die, in the process of coining. There is, in most cases, a limit beyond which, when the pressure is increased, bodies are fractured or reduced to powder.

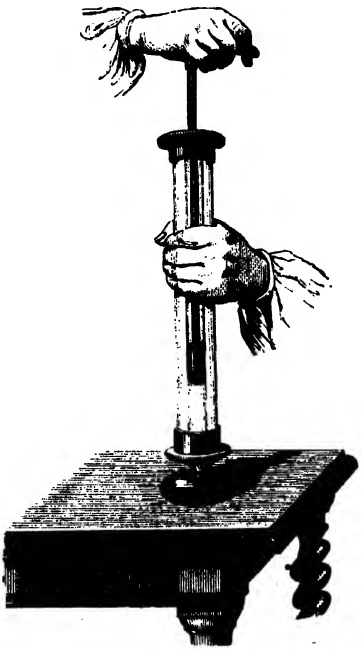


Fig. 4.

The compressibility of liquids is so small as to have remained for a long time undetected: it may, however, be proved by experiment, as will be seen in the chapter on HYDROSTATICS.

The most compressible bodies are gases, which by pressure may be made to occupy ten, twenty, or a hundred times less space than under ordinary circumstances. The great compressibility of gases may be demonstrated by means of a glass tube with very thick sides, closed at one end and provided with a tight-fitting solid piston (fig. 4). The enclosed air cannot escape, and yet when the handle of the piston is pressed it can be moved down to one-half to three-quarters the length of the tube; proving that the volume of

the air is reduced necessarily to half or a quarter what it was originally. Most gases when thus compressed exhibit a remarkable property to which we shall revert, that, namely, of *liquefying*, or passing from the gaseous to the liquid state.

12. **Elasticity.**—*Elasticity* is the property which bodies possess of resuming their original form or volume, when, after having been compressed, bent, twisted, or pulled, the force which altered them has ceased to act.

Four kinds of elasticity may be distinguished; the elasticity by *pressure*, as in the case of gases; the elasticity by *flexure*, observed in springs; the elasticity of *torsion*, which is produced in linen or cotton threads when they are untwisted; and, finally, the elasticity of *tension*, which is that of piano or violin strings when they are stretched.

Elasticity, of whatever kind, is the result of a molecular displacement. If the molecules have been approximated by pressure, the repulsive force of heat tends to separate them; if, on the contrary, they have been separated, molecular attraction tends to bring them near each other again. If a piece of whalebone be bent, the molecules in the concave part being compressed repel each other; in the convex part, where they are separated, they tend to approach each other; both these actions tend, therefore, to straighten it as soon as it is free.

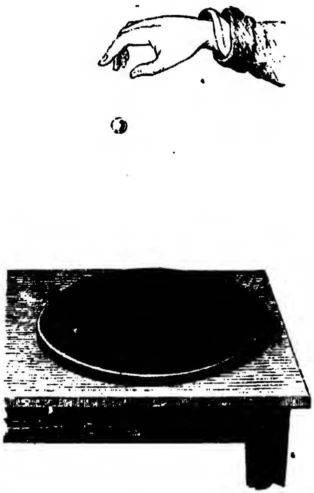


Fig. 5.

Gases and liquids are perfectly elastic; in other words, they regain exactly the same volume when the pressure becomes the same. Solid bodies present different degrees of elasticity, though none present the property in the same perfection as liquids and gases, and in all it varies according to the time during which the body has been exposed to pressure. Caoutchouc, ivory, glass, and marble possess considerable elasticity; lead, clay, and fats, scarcely any.

There is a limit to the elasticity of solids, beyond which they either break or are incapable of regaining their original form and volume. In sprains, for instance, the elasticity of the tendons has been exceeded. In gases and liquids, on the contrary, no such limit can be reached; they always regain their original volume.

The elasticity of solids may be demonstrated by the following experiment:—On a slab of polished black marble thinly smeared with oil, an ivory ball is allowed to drop from gradually increasing heights. Each time it will rebound and rise to a height a little less than that from which it fell, after having formed on the layer of oil a circular impression which is larger the greater the height of the fall (fig. 5). From this we conclude that the ball was flattened each time, and that it rebounded in consequence of the reaction of its compressed molecules.

13. **Applications of elasticity.**—Numerous applications of elasticity may be given. It is owing to their elasticity that corks are used for closing bottles. Pushed into the neck by the exercise of a certain force they become compressed, and then their elasticity causing them to press against the sides, they completely close the neck.

Children's balls depend upon the elasticity of gas: they are made of caoutchouc, and are inflated by air; when they strike against the ground, or against a wall, their volume diminishes, and the air which they contain being suddenly compressed, expands, and, acting like a spring, makes the ball rebound. A similar application is met with in air-cushions. They are made of an air-tight material, and are also inflated by air; they are at once compressible and elastic, and form a very soft seat.

Air-guns are a further application. The breech in these is made of steel, and is hollow; air is compressed in it by means of an instrument called the *compression-pump*, and being suddenly liberated its expansive force is sufficient to expel the projectile.

The use of carriage, and of watch and clock, springs depends upon the elasticity of steel. In like manner the elasticity of wool, hair, feathers, is utilised in mattresses, pillows, and seats.

Lastly, it is owing to their elasticity that piano, guitar, or violin strings are capable of being put into a vibratory motion, which, as we shall prove, is the origin of the sounds which stringed instruments yield.

CHAPTER III.

MOTION AND FORCE.

14. **Rest and motion.**—To understand what we have to say about inertia, weight, universal gravitation, and the motion of liquids and gases, it is first of all necessary to give some very elementary notions about motion and force.

A body is said to be at *rest*, when it remains in the same place; to be in *motion* when it passes from one place to another. Both rest and motion are either absolute or relative.

Absolute rest would be the entire absence of motion. No such condition, however, is known in the universe; for the earth and the other planets rotate both about the sun and about their own axes; and therefore, all the parts composing them share this double motion. Even the sun itself has a motion of rotation which excludes the idea of absolute rest.

Relative or apparent rest is the condition of a body which appears fixed in reference to surrounding objects, but which really shares with them a double motion. For instance, a passenger in a railway carriage may be in a state of relative rest with respect to the train in which he travels, but he is in a state of relative motion with respect to the objects (fields, houses, etc.) past which the train rushes. These houses again enjoy merely a state of relative rest, for the earth itself which bears them is in a state of incessant relative motion with respect to the celestial bodies of our solar system.

The absolute motion of this passenger would be that measured in regard to a fixed point in space, which cannot be realised, for we know no such point. In short, absolute motion and rest are unknown to us; in nature, relative motion and rest are alone presented to our observation.

15. **Different kinds of motion.**—Motion is either rectilinear or curvilinear: *rectilinear* when the moving body travels along a straight line, as when a body falls to the ground; *curvilinear* when it goes along a curved line, as in the case of a horse turning in a mill.

Each kind of motion is either *uniform* or *varied.*

16. **Uniform motion.**—Motion is said to be uniform when the moving body passes over equal spaces in equal intervals of time; such, for instance, as the motion of a water-wheel when it makes exactly the same number of turns in a minute. Such, again, is the motion of the hands of a watch. A regiment of soldiers marching in step affords an example of uniform motion.

The *velocity* of motion is the space traversed in a given time, a second or an hour, for example. A train which moves thirty miles in each successive hour is said to have a velocity of thirty miles an hour.

17. **Varied motion.**—Varied motion is that in which unequal spaces are traversed in equal times. If the spaces traversed in the same time go on increasing, the motion is said to be *accelerated;* such is the motion of a train starting from a station; if the spaces decrease, as is the case when the trains come into a station, the motion is retarded.

If the distances, traversed in equal times, always increase by the same amount, the motion is said to be *uniformly accelerated*; if, on the other hand, they constantly decrease by the same amount, the motion is *uniformly retarded.* We shall soon see examples of these kinds of motion in the case of falling bodies.

18. **Inertia.**—*Inertia* is a purely negative property of matter; it is the incapability of matter to change its own state of motion or rest.

Daily observation shows that a body never spontaneously passes from a state of rest into one of motion. Bodies in falling to the ground seem to set themselves in motion. This is, however, not in consequence of any inherent property; but, as we shall afterwards see, because they are acted upon by the force of gravity.

Not merely do bodies at rest persist in a state of rest, but bodies in motion continue to move. This principle may seem less obvious than the former, because we are accustomed to see many bodies gradually move more slowly, and ultimately stop, as is the case with a billiard ball for example. But this is not due to any inherent preference for a state of rest on the part of the billiard ball, but because its motion is impeded by the friction of the cloth on which it rolls, and by the resistance of the air. The smaller these resistances, the more prolonged is its motion; as is observed, for instance, if a ball be set rolling on a smooth sheet of ice. If all impeding causes were removed, a body once in motion would continue to move for ever.

19. **Effects due to inertia.**—Innumerable phenomena may be explained by the inertia of matter. For instance, before leaping a ditch we run towards it, in order that the motion of our bodies at the time of leaping may add itself to the muscular effort then made.

On descending carelessly from a carriage in motion, the upper part of the body retains its motion, whilst the feet are prevented from doing so by friction against the ground; the consequence is we fall towards the moving carriage.

If a man in running strikes his foot against an obstacle he is apt to fall down in front, because the rest of his body tends to retain the motion it has acquired. When a horse at full gallop suddenly stops, if the rider does not hold fast with his knees, he is thrown over the horse's head in virtue of his inertia.

The terrible accidents on our railways are chiefly due to inertia. When the motion of the engine is suddenly arrested the carriages strive to continue the motion they had acquired, and in doing so are shattered against each other.

The action of projectiles is another case. When a bullet traverses a wall, or cuts a tree in two, it is owing to its tendency to retain the velocity which the explosion of the powder had imparted to it. In the action of hammers and of pile driving we have analogous cases.

20. **Forces, powers, resistances.**—Bodies being of themselves inert, and having no tendency to change either their state of rest or that of motion, any cause capable of making them pass from a state of rest to one of motion, or conversely from a state of motion to one of rest, is called a *force*.

The attractions and repulsions exerted between the molecules are forces; the muscular action which men and animals bring into play is a force, as is also the elasticity of gases and vapours which we shall subsequently discuss.

The forces which tend to produce motion are called *powers;* those which tend to destroy motion are called *resistances.* Thus, when a man drags a burden along the ground his muscular force is a power, while the friction of the burden against the ground is a resistance.

Forces of the kind called powers are always tending to accelerate motion, and are called *accelerating forces.* Resistances on the contrary, always tending to retard it, are called retarding forces.

21. **Distinctive characters of forces.**—Three things are to be

distinguished in each force; the point of application, the direction, and the intensity.

The *point of application of a force* is the point at which it exerts its action. Having attached a cord to a carriage, as shown in fig. 6, the point of application is the point A, at which the cord is actually attached.

The *direction of a force* is the right line along which it urges or tends to urge the point of application. In fig. 6 the cord AB represents the direction of the force.

The *intensity of a force* is its energy, its magnitude, or value, in reference to a certain standard. In fig. 6, which represents a boy

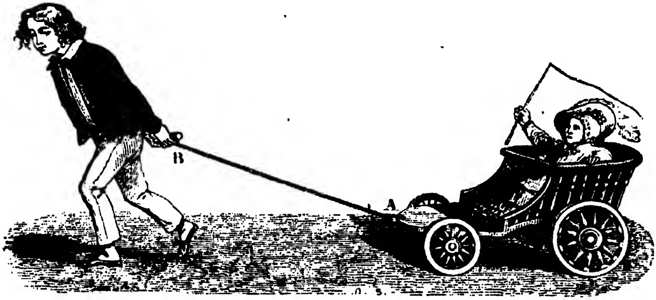


Fig. 6.

drawing a small carriage, a certain exertion of force is required on the part of the boy; if the carriage were loaded twice or thrice as much, the force required must be twice or thrice as great.

22. **Measurement of forces. Dynamometer.**—The force which a motor developes in pushing or drawing a body, is measured by the number of pounds necessary to produce the same pressure or the same pull; so that a force is said to be a force of 40 or 50 pounds, when it can be replaced by the action of a weight of 40 or 50 pounds.

The weight which thus represents the intensity of a force is determined by means of the *dynamometer*. There are several forms of this instrument, one of the simplest being that represented in fig. 7. It consists of a V-shaped plate of tempered steel, AB. At one end of the limb B is fixed an iron arc, *n*, which passes freely through an aperture at the end of the limb A. To this latter is fixed an arc, *m*, fitting in the same manner in the limb B. The arc *m* is provided at the end with a crook, and *n* with a ring, and on

the latter *n* there is a graduation obtained in the following manner :—

The apparatus being fixed to a resisting support, weights of 1, 2,

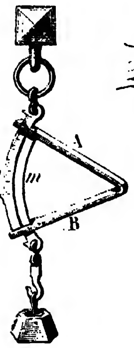


Fig. 7.

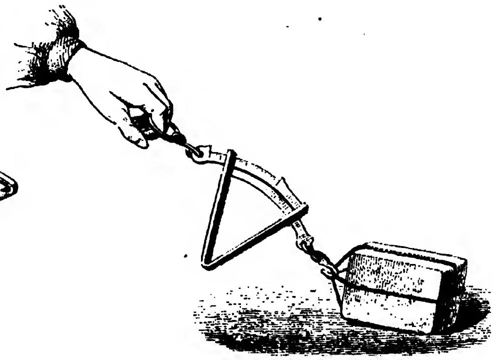


Fig. 8.

3, 4, or more pounds are successively suspended to the crook. The limb B, supported by the arc *n*, remains fixed, while the limb A, being moved by the weight attached to the arc *m*, is lowered to an extent dependent on the weight. The load is gradually increased until it has reached the utmost limit possible without breaking, care being taken at each load to mark a line on the arc *n* at the point at which the limb A stops.

In order to apply it to the measurement of forces, to estimate, for instance, the effort necessary to drag a load (fig. 8), the crook of the arc *m* is fixed to the load, then holding in the hand the ring of the arc *n* it is pulled until the load is moved. The flexure of the limb A marks on the arc *n* the value in pounds of the effort of traction.

The apparatus described is also used as a balance to determine the weight of bodies, and is known as *the steelyard*.

Forces once measured in weight, they may be represented as to their intensity by means of the line which indicates their direction. For this purpose a length is measured off on this line, starting from the point of application, which contains the unit of length as many times as the intensity of the force contains pounds. Thus, if in fig. 6 the effort of traction is 15 pounds, a length, AB, would be measured from A equal to 15 times the unit of length, which may be an inch for distance. Thus the work of

the boy in drawing the carriage would be represented both in direction and intensity by the line AB.

23. **Resultant and component forces.**—When a body is acted upon by only a single force, it is clear that, if it is not hindered by any obstacle, it will move in the direction of this force; but if it is simultaneously acted upon by several forces in different directions, its direction will not, speaking generally, coincide with that of any of these forces. If two men, for example, on the banks of a river, tow a boat by means of ropes, as shown in fig. 9, the boat follows

Fig 9.

neither the direction AB, nor the direction AC, in which these men are respectively pulling, but takes an intermediate direction, AE; that is, it moves as if it were acted upon by a single force in the direction AE.

The single force, which we conceive as having the direction AE, producing the same effect as the forces of traction of these two men, is called the *resultant* of these two forces; and conversely these, in reference to their resultant, are spoken of as the *components*.

24. **Value of the resultant of two concurring forces. Parallelogram of forces.**—When two forces having different directions are applied to the same point of a body, as represented in fig. 9, there is a very simple ratio between their intensities and that of their resultant, which is of great importance from the number of its application.

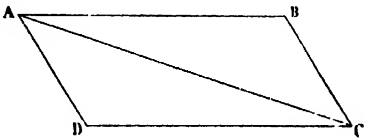


Fig 10.

It will first of all be necessary to define the word *parallelogram*,

of which we shall make use. The parallelogram is a geometrical figure, formed of four right lines, each pair of which is parallel (fig. 10), that is, the two lines AB and CD are parallel, and also the lines AD and BC. These lines form the sides of the parallelogram, and the points A, B, C, D, the angles. The *diagonal* is the line, like AC, joining two opposite angles A and C.

In treatises on mechanics proofs are given of the following important theorem, which is known as the *principle of the parallelogram of forces* :

When two forces applied at the same point A (fig. 11) *are represented in direction, and in intensity by the sides* AB *and* AD *of the*

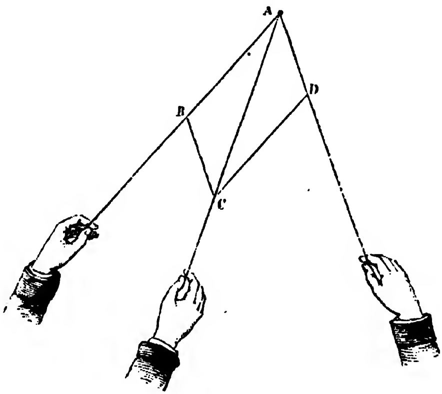


Fig. 11.

parallelogram ABCD, *their resultant is represented both as to its intensity and direction by the diagonal* AC *of this parallelogram.*

That is, that the point A being simultaneously acted upon by two forces, whose directions and intensities are respectively represented by AB and AD ; this point moves in the direction AC exactly as if it were acted upon by a single force, the direction and intensity of which are represented by the line AC.

Frequent applications are met with of the principle of the parallelogram of forces. Thus, in the flight of a bird, when the wings strike against the air, a resistance is offered which is equal to an impulsive force from back to front in the directions AH and AK (fig. 12) ; hence representing, by AB and AD, the intensities and directions of these impulsive forces, if the parallelogram be completed,

we shall find that the resultant, or the single force which makes the bird advance, is represented in direction and magnitude by the

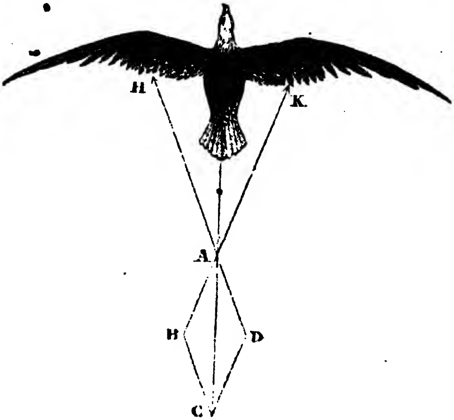


Fig. 12.

diagonal AC. The same reasoning applies to the swimming both of men and fishes.

25. **Another effect of the parallelogram of forces.**—We have seen that, in accordance with the principle of the parallelogram of forces, two forces applied at the same point of a body may be re-

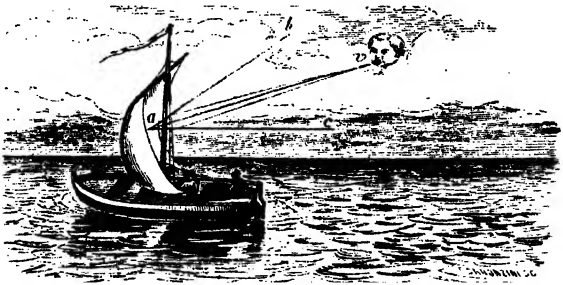


Fig. 13.

duced to a single one. By the aid of the same principle a single force applied to a body may be replaced by two other forces pro-

ducing together the same effect as the first. This force is then said to be *decomposed* into two others.

It is but seldom indeed that the action of a force is entirely utilised ; it may almost always be decomposed into two others, only one of which produces a useful effect. Thus when the wind blows against the sails of a vessel, not quite directly, but a little on one side, as shown in fig. 13, the effect of the wind in the direction *va* may be decomposed into two others, one in the direction *ca*, and the other in a lateral direction *ba*. The first moves the vessel, the second only guides it.

26. **Case in which the forces are parallel. Value of the resultant.**—In the case of the boat drawn by a rope (fig. 9), the forces were *concurrent*, that is, their directions if produced would meet in one point ; but it may happen that the forces applied to the same body are parallel, and then two cases present themselves ; that is, they either act in the same direction as in the case of two horses drawing a carriage ; or they may act in opposite directions, when a steamer for instance ascends a river, the current acts in opposition to the force which urges the steamer. It can be proved that, in the first case, *the resultant of the forces is equal to their sum* ; and that in the second *it is equal to their difference.*

27. **Equilibrium of forces.**—When several forces act upon a body at the same time, they do not always put it in motion ; it may happen that while some of these forces tend to produce motion in a certain direction, the others tend to produce an equal and contrary motion in the opposite direction. It is clear that in this case, since the forces just neutralise each other, no effect can be produced. Whenever several forces applied to the same body thus mutually destroy each other, we have what is called *equilibrium.*

The simplest case of equilibrium is that of two equal and opposite forces applied at the same point of a body. For instance, if two men pull at a cord with the same intensity, one in one direc-

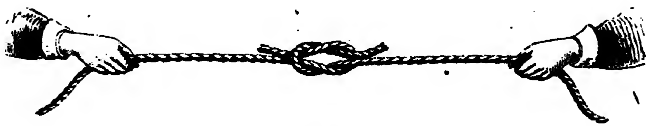


Fig. 14.

tion, and the other in the opposite one, equilibrium will be produced (fig. 14). In like manner if, in a well, two buckets of the same size

each full of water, are suspended at the end of a rope which passes round a pulley, the weight of one holds the other in equilibrium.

The bodies which we consider ordinarily to be in a state of rest, are really in a state of equilibrium. For instance, when a body rests on a table, there is equilibrium between the force of gravity which tends to make the body fall, and the resistance which the table offers to the fall. If the weight of the body exceeds this resistance, equilibrium is destroyed, the table is broken, and the body falls.

28. **Centrifugal force.**—We shall conclude these notions about forces by mentioning a force to which curvilinear motion is due, namely *centrifugal force*. This may be explained as follows. Whenever a body has been put in motion in a particular direction, in virtue of its inertia, it tends always to move in this direction. Hence whenever a line is seen to move in a circle, this can only be

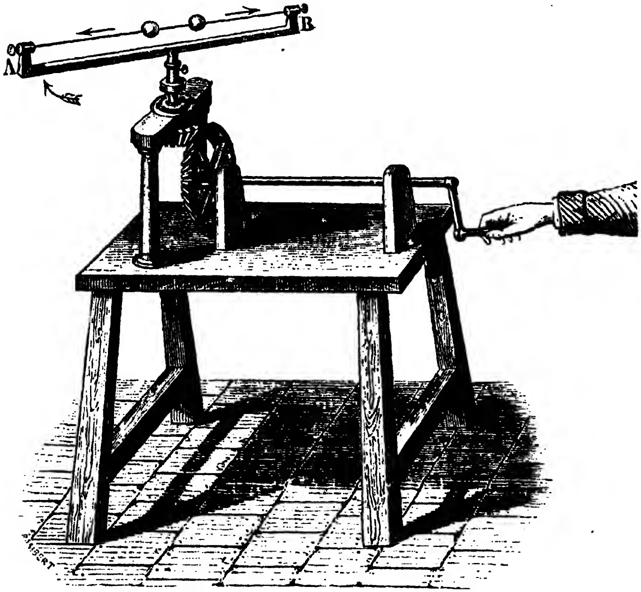


Fig. 15.

due to some obstacle, or some new force which deviates it. In fact, since a curved line may be considered to consist of a series of

infinitely small straight lines, the moving body, owing to its inertia, always tends to follow the prolongation of the small straight line which it traverses. It tends then to retain its motion in a straight line, and to fly from the curve which it is compelled to describe. This action is called the *centrifugal* force, from two Latin words which signify to fly from the centre.

The production of centrifugal force in circular motion may be demonstrated by means of the apparatus represented in fig. 15. On a brass frame AB is stretched a stout brass wire, and on which are slid two ivory balls which can move freely along the wire: the balls being arranged as shown in the figure, the frame is rapidly rotated by means of the *turning table*. The balls, projected by the centrifugal force, glide along the wire; and strike the ends with the greater force, the greater the velocity of rotation.

29. **Effects of centrifugal force.**—The centrifugal force is greater the greater the velocity, and the more marked the curvature of the line along which the movable body passes. Hence railways should be as straight as possible, for as the trains have a great velocity, when they move along a curve the centrifugal force is continually tending to throw them off, and the more so the sharper the curve.

It is owing to centrifugal force that the wheels of a carriage moving along a muddy road throw off the mud that adheres to the rim.

In a circus, the horses and their riders always incline their bodies towards the centre, and the greater their speed the greater their inclination. The object of this is to allow their weight to counteract the influence of the centrifugal force, which would throw them off if they stood upright.

In sugar refineries centrifugal force is applied in removing syrup from crystallised sugar. The sugar is placed in a cylindrical vessel, whose sides are made of wire gauze, and which is put in rapid rotation. The centrifugal force scatters the coloured syrup through the meshes of the sieve, while the solid crystals are left behind colourless and pure. The same principle is applied in drying clothes in large washing establishments. A wet mop made to turn quickly about its own handle as an axis throws the water off on all sides, and quickly dries itself.

A hoop trundled along the ground may move for a long time before falling, but if we attempt to keep it upright while in a state of rest, it at once falls. The reason of this is that, while in motion; if

it inclines to one side, the inclination causes it to describe a curved line, whence arises a centrifugal force which opposes the fall of the hoop at any rate so long as it retains a sufficient velocity.

30. **Flattening of the earth at the poles.**—One of the most remarkable effects of centrifugal force is the flattening of the earth at the two poles. To explain this phenomenon we must premise that the earth, which is nearly spherical in form, rotates about an imaginary axis passing through its two poles, and that, in this rotation, all points on the surface have not the same velocity, for they do not describe the same paths. For at the equator they describe every twenty-four hours a circumference equal to that of the earth, while points taken at increasing distances from the equator gradually describe smaller and smaller circles to the poles where they have no motion. Hence owing to the diurnal rotation about the earth's axis, a centrifugal force is produced which is greatest at the equator, and gradually diminishes up to the poles where there is none at all. Hence, owing to this inequality in the intensity of the centrifugal force, there must arise an accumulation of matter about the equator, especially if, as geologists assume, the earth was originally in a state of fusion.

It has in fact been ascertained by direct measurement, that the radius of the earth at the poles is less than that at the equator by about $\frac{1}{289}$ the latter, or $13\frac{1}{2}$ miles. A similar flattening has been observed in other planets.

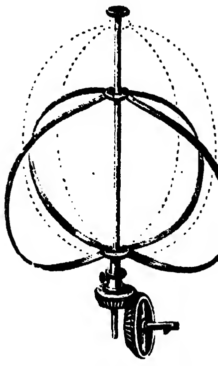


Fig. 16.

To demonstrate this bulging at the equator and flattening at the poles, use is made of the apparatus represented in fig. 16. It consists of an iron rod, which may be fixed upon the turning table, instead of the piece A B (fig. 15). At the bottom of the rod are fixed four thin elastic metal plates, which are joined at the top to a ring which can slide up and down the rod. The apparatus being then put in rapid rotation, the rings slide down the rod as represented in the figure to an extent depending on the rapidity of the rotation.

LEVERS.

31. **Mechanics. Machines.**—*Mechanics* is the Science which treats of forces and of motion. Several forces being applied to the same body, it indicates the relation which must exist between them in order to produce equilibrium, or in order to produce a given effect.

Any apparatus which serves to transmit the action of a force is a *machine*; and any force which moves a machine is a *motor*. In cutting an apple with a knife, the hand is the motor, and the knife which transmits its action is a machine. A horse drawing a cart is a motor, and the cart which utilises the force of the horse in conveying loads is a machine. The watercourse which works a wheel, the wind which turns a mill, and the steam which moves a locomotive, are all motors; and the water-wheel, the wind-mill, and the locomotive are all machines.

Machines do not increase the force of a motor; but, by modifying its action, they render it capable of performing work which it alone could not do. For instance, by the aid of a lever, a man can raise burdens, which, without such help, would be impossible. We shall only describe here the lever, the simplest of all machines, and shall afterwards see its action in the case of balances.

32. **Levers.**—A lever is a rigid bar of wood or of metal moveable about a fixed point or edge called the *fulcrum*; and subject to the action of two forces which tend to move it in opposite directions. The force which acts as motor is called the *power*, and the other the *resistance*. Levers are divided into three classes, accord-

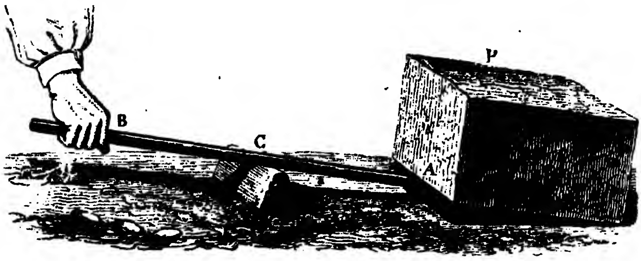


Fig. 17.

ing to the different positions of the power, and resistance in reference to the fulcrum.

A lever of the first kind is one in which the fulcrum is between the power and the resistance. Fig. 17 represents one of this kind,

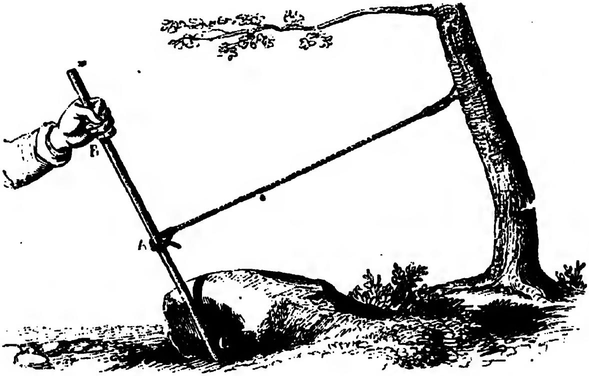


Fig. 18.

in which the hand is the power, the weight P the resistance, while C is the fulcrum.

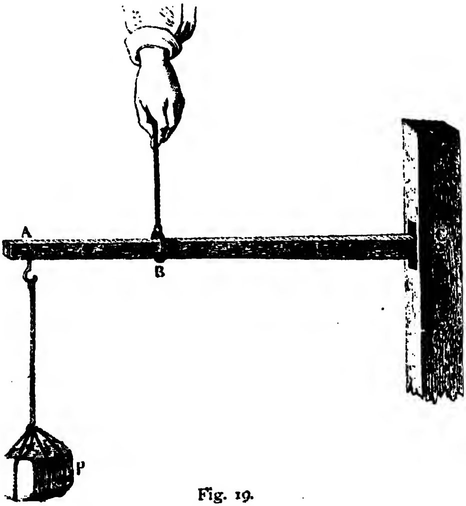


Fig. 19.

A lever of the second kind has the resistance between the power and the fulcrum, as in fig. 18.

A lever of the third kind is one in which the power is applied between the resistance and the fulcrum as represented in fig. 19.

In these different kinds of levers, the distances from the fulcrum to the power and to the resistance are called the *arms of the lever*. In fig. 19, for instance, the arm of the power is the distance from C to B, and that from C to A is the arm of the resistance.

33. **Effect of levers. Condition of equilibrium.**—It may be shown that the effect produced by a force by means of a lever, increases with the length of the arm upon which it acts, that is, if the arm is twice, thrice, or four times as long, the useful effect is two, three, or four times as great. This is what led Archimedes to say, that, give him a fulcrum, and he would lift the world.

Since a force produces a greater effect the longer the arm of the lever, it follows that in order to produce equilibrium between the power and the resistance, acting at the same time on a lever, if the arms are equal, *the two forces themselves must be equal*, and that if the arms of the lever are unequal, *the two forces must be inversely as the arms of the lever*; thus, if the power is one-third that of the resistance, the arm of the power should be three times as long as that of the resistance.

In a lever of the third kind the power must be always greater than the resistance, for the distance of the resistance from the fulcrum (AC, fig. 19) is always greater than the distance BC from the power B to the fulcrum. In a lever of the second kind the power is always smaller than the resistance, for the arm BC is longer than the arm AC (fig. 18). These properties are expressed by saying that, in a lever of the third kind, there is a loss of power, and in one of the second kind a gain. In a lever of the first kind there may be either gain, or loss, or they may just balance each other, for the arm BC of the power (fig. 17) may be either greater, or less than, or equal to, the arm AC.

34. **Various applications of levers.**—Numerous applications of the different kinds of levers are met with in articles of every-day use. The ordinary balance (fig. 34) is a lever of the first kind, as is also a

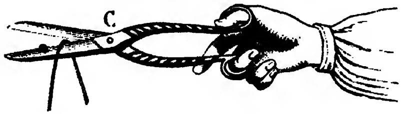


Fig. 20.

pump handle. Scissors are another instance; each handle is a lever, the fulcrum of which is the pivot C, the power is the hand, and the resistance is the material to be cut (fig. 20).

As levers of the second class may be enumerated the oars of a boat. The resistance of the water to the motion of the feather of the oar represents the fulcrum, the hand of the oarsman is the power, and the boat, or rather the water it displaces, is the resistance. The knife fixed at one end and used in slicing roots, or cutting bread, is a lever of the second kind. Nutcrackers (fig. 21) afford a third illustration, as also does the common wheelbarrow.

Fig. 21.

The third kind of lever is less frequently met with. The pedals used in pianos and in grindstones are instances. In the latter case the pedal consists of a wooden board AC (fig. 22) forming a lever.

Fig. 22.

The fulcrum is at C on a bolt fixed to the frame; the power is the foot of the man turning, and the resistance, which is the motion to be transmitted to the wheel, is applied at A by means of a rod joined to a crank in the centre of the mill.

In the common fire-tongs each leg is a lever of the third kind.

The hand of a man pushing open a gate while standing near the hinges moves through much less space than the end of the gate, and must act, therefore, with greater force.

The most beautiful and numerous instances are met with in the muscular system of men and animals, almost all motions of which are effected by this mechanism.

CHAPTER IV.

35. **Universal attraction.**—It is stated that Newton, sitting one day in his garden saw an apple fall from a tree, was led by this circumstance to reflect upon the cause why bodies fell to the ground, and ultimately to the discovery of the important laws which govern the motion of the earth and of the stars.

They may be thus stated :

1. *All bodies in nature exert a mutual attraction upon each other at all distances, in virtue of which they are continually tending towards each other.*

2. *For the same distance the attractions between bodies are proportional to their masses.*

3. *The masses being equal the attraction varies with the distance, being inversely proportional to the square of the distances asunder.*

To illustrate this, we may take the case of two spheres which, owing to their symmetry, attract each other just as if their masses were concentrated in their centres. If without other alteration the mass of one sphere were doubled, trebled, etc., the attraction between them would be doubled, trebled, etc. If, however, the mass of one sphere being doubled, that of the other were increased three times, the distance between their centres remaining the same, the attraction would be increased six times. Lastly, if, without altering their masses, the distance between their centres were *increased* from 1 to 2, 3, 4, . . . units, the attraction would be diminished the 4th, 9th, 16th . . . part of its former intensity.

36. **Gravitation.**—The term *gravitation* is applied more especially to the attraction exerted between the heavenly bodies. The sun, being that member of our planetary system which has the largest mass, exerts also the greatest attraction, from which it might seem that the earth and the other planets ought to fall into the sun in virtue of this attraction. This would indeed be the case,

if they were only acted upon by the force of gravitation; but owing to their inertia, the original impulse which they once received, constantly tends to carry them away from the sun in a straight line. This acquired velocity, combined with gravitation, makes the planets describe curves about the sun which are almost circular and are called their *orbits*.

37. **Gravity.**—This is the force in virtue of which bodies *fall* when they are no longer supported, that is, tend towards the centre of the earth. It is a particular case of universal attraction; and is due to the reciprocal attraction exerted between the earth and bodies placed on its surface: it acts equally upon all bodies, whether they are at rest or in motion; whether they are solids, liquids, or gases. Some bodies, such as clouds and smoke, appear not to be influenced by this force, for they rise in the atmosphere instead of sinking; yet this, as will afterwards be seen, is no exception to the action of gravity.

Gravity, being a particular case of universal attraction, acts upon bodies proportionally to their mass and inversely as the square of their distance; that is, a body which contains twice or thrice as much matter as another, is attracted by the earth with a twofold or threefold force; or, in other words, weighs twice or thrice as much. In like manner one and the same body could be moved to twice or thrice its present distance from the *centre* of the earth, it would have one-fourth or one-ninth of its present weight; we say the *centre* and not the *surface* of the earth, for it is demonstrated in treatises on mechanics that the attractive force of the earth which causes bodies to fall must be calculated from its centre.

From the magnitude of the earth's radius, which is about 4,000 miles, all bodies on its surface may be considered to be virtually at the same distance from the centre, and we may therefore conclude that their difference in weight is merely due to their difference in mass.

38. **The weight of a body increases from the equator to the poles.**—The force which makes bodies fall is not exactly the same at all points of the earth's surface. Two causes make it increase from the equator to the poles: the daily rotation of the earth about its axis, and the flattening at the poles. For the rotation of the earth gives rise to a centrifugal force acting from the centre to the surface, that is, in the opposite direction to the force of gravity. Hence bodies are continually acted upon by two forces in opposite directions; the force of gravity which draws them towards the centre, and the centrifugal force which tends to drive them away

from it. So that it is really the excess of the second force over the first which makes bodies fall. But as the centrifugal force decreases from the equator to the poles (30), the excess of gravity over this force becomes greater, and thus the weights of bodies increase as they come nearer the poles.

The flattening of the earth concurs in producing the same effect; for, in consequence of it, bodies placed on the surface of the earth are nearer the centre at the poles, than they are at the equator, and are therefore more attracted. It must be added, that the increase in weight due to these two causes is very small, and is inappreciable by ordinary balances.

39. **Vertical and horizontal lines.**—At any point of the earth's surface, the direction of gravity, that is, the line which a falling body describes, is called the *vertical* line. The vertical lines drawn at different points of the earth's surface converge very nearly to the earth's centre. Hence, owing to the great distance from the surface of the earth to its centre, for points on the surface *a* and

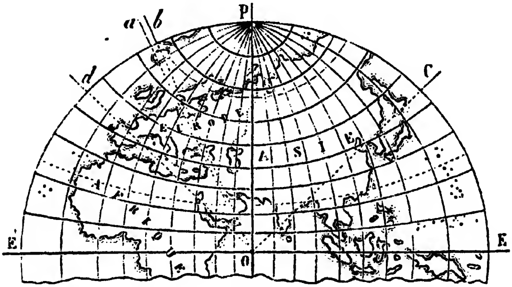


Fig. 23.

b (fig. 23), not far apart, these verticals may assume to be parallel; but they are less parallel the further apart the points, as shown by the verticals *a* and *d*. For points situated on the same meridian the angle contained between the vertical lines equals the difference between the latitudes of those points.

At each point on the surface of the earth a man standing upright is in the direction of the vertical. But, as we have just seen, this direction changes from one place to another, and the same is the case with the position of the inhabitants of the various countries on the earth. As the earth is spherical, it follows that at two points, exactly opposite, two men will be in inverted positions in reference

to each other; from which is derived the term *antipodes* (opposite as regards the feet), given to the inhabitants of two diametrically opposite places.

A plane or a line is said to be *horizontal* when it is perpendicular to the direction of the vertical. The surface of water in a state of equilibrium is always horizontal. In speaking of the *level* we shall learn how the horizontality of any surface or line is determined.

40. **Plumb-line.**—The vertical line at any point of the globe is generally determined by the *plumb-line* (fig. 24), which consists of a cylindrical weight attached to the end of a string. In obedience to the action of gravity this weight draws the string in the direction of this force, and when it is at rest the string is in the vertical direction. To ascertain by the aid of the plumb-line whether a given surface, a wall for example, is vertical, a small metal plate is used,

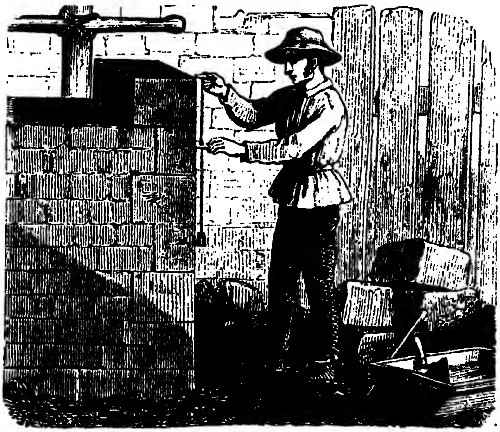


Fig. 24.

the side of which is equal to the diameter of the weight. In the centre of this plate is a small hole, through which passes the string: holding in one hand the plate, and in the other the string, the edge of the plate is placed against the wall (fig. 24); if the weight just touches it the wall is vertical; if the cylinder does not touch the wall, it shows that the wall is inclined outwards; it is inclined inwards if the weight touches the wall when the plate is a little removed from it.

41. **Weight of a body.**—The *weight* of a body is the sum of

the partial attractions which the earth exerts upon each of its molecules. Hence the weight of a body must increase as its mass does; that is, if it contains twice or thrice as much matter, its weight must be twice or thrice as great. The weight of a body is not to be confounded with *gravity*: this is the cause which produces the fall of bodies; the weight is only the effect. We shall presently see how weight is determined by means of the balance; gravitation is measured by the aid of the pendulum.

42. **Centre of gravity.**—We have seen that all the partial attractions which the earth exerts upon each of the molecules of a body are equivalent to a single force which is the weight of the body. Now it may be shown in mechanics, that whatever be the shape of any body, there is always a certain point through which this single force, the weight acts, in whatever position the body be placed in respect to the earth; this point is called *the centre of gravity* of the body.

To find the centre of gravity of a body is a purely geometrical problem; in many cases, however, it can be determined immediately. For instance, the centre of gravity of a right line of uniform density is the point which bisects its length; in the circle and sphere it coincides with the geometrical centre; in cylindrical bars it is the middle point of the axis; in a square or a parallelogram it is at the point of intersection of the two diagonals. These rules, it must be remembered, presuppose that the several bodies are of uniform density.

43. **Experimental determination of the centre of gravity.**—The centre of gravity of a body may also be found by experiment.

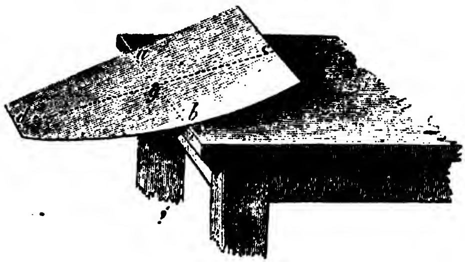


Fig. 25.

When its weight is not too great it is suspended by a string in two different positions; the centre of gravity of the body is necessarily below the point of suspension, and therefore in the prolonga-

tion of the vertical cord which sustains it. If then, in two different positions, the vertical lines of suspension be prolonged, they cut one another, and the point of intersection is the centre of gravity sought.

In the case of these flat substances, like a piece of cardboard or a sheet of tin plate, the centre of gravity may be found by balancing the body in two different positions on a horizontal edge; for instance, sliding them near the edge of a table until they are ready to turn in either direction (fig. 25). The centre of gravity is then on the line *ab*. Seeking, in a similar manner, a second position of equilibrium in which the line of contact is *cd* for instance, the centre of gravity must necessarily be on both these lines, that is, must be at the point of their intersection *g*; or, more accurately, a little below this point, in the interior of the body, and at an equal distance from its two faces.

If the body be thicker, three positions of equilibrium must be found; the centre of gravity is then at the point of intersection of the three planes passing vertically through the lines of contact when the body is in equilibrium.

Fig. 26.

44. **Equilibrium of heavy bodies.** — As the centre of gravity is the point where the whole action of gravitation is concentrated, it follows that whenever this point rests upon any support, the action of gravitation is destroyed, and therefore the body remains in equilibrium. There are, however, several cases, according as the body has one or more points of support.

Where the body has only one point of support equilibrium is only possible when the centre of gravity either coincides with this point, or is exactly above or below it in the same vertical line; for then the action of gravitation is destroyed by the resistance of the fixed point through which this force passes. The

plumb-line (fig. 24) is a case of this kind, the centre of gravity being below the point of support. Another example is met in the case of a stick balanced on the finger, as seen in fig. 26, in which the letter *g* indicates the position of equilibrium exactly over the point of support.

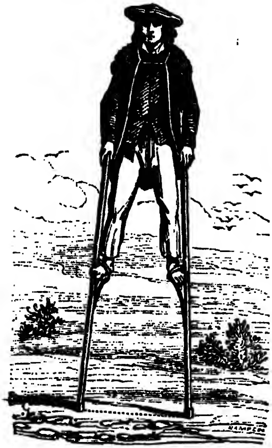


Fig. 27.

If the body has two points of support, it is not necessary for equilibrium that its centre of gravity coincide with either of these points, or be exactly above or below: it is sufficient if it be exactly below or above the right line which joins these two points, for the action of gravitation may then be decomposed into two forces applied at the points of support, and destroyed by the resistance of these points. A man on stilts (fig. 27) is an example of this case of equilibrium.

Lastly, if a body rests on the ground by three or more points of support (fig. 28), equilibrium is produced whenever the centre of gravity is above the *base* formed by these points of support, that is, whenever the vertical let fall from the centre of gravity to the earth is within the points of support; for gravitation cannot then overturn the body beyond its points of support, and its only effect is to settle it more firmly on the ground.

Fig. 28.

45. **Different states of equilibrium.** — Although a body supported by a fixed point is in equilibrium whenever its centre of gravity is in the vertical line through that point, the fact that the centre of gravity tends incessantly to occupy the lowest possible position leads us to distinguish between three states of equilibrium — ***stable, unstable, neutral.***

A body is said to be in ***stable equilibrum*** if it tends to return to its first position after the equilibrium has been slightly disturbed. Every body is in this state when its position is such that the slightest alteration of the same elevates its centre of gravity; for the centre of gravity will descend again when permitted, and after a few oscillations the body will return to its original position.

The pendulum of a clock continually oscillates about its position of stable equilibrium, and an egg on a level table is in this state when

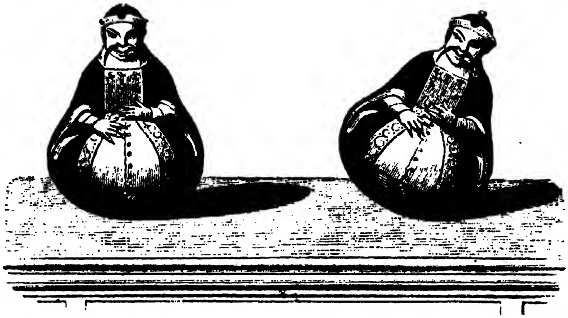


Fig. 29.

its long axis is horizontal. We have another illustration in the toy represented in fig. 29.

These little figures, which are hollow and light, are loaded at the base with a small mass of lead, so that the centre of gravity is very low. Hence when the figure is inclined, the centre of gravity is raised, and gravitation tending to make it descend, the figure reverts to its original position after a number of oscillations on the right and left of its final position of equilibrium.

A body is said to be in ***unstable equilibrium***, when, after the slightest disturbance, it tends to depart still more from its original position. A body is in this state when its centre of gravity is vertically above the point of support, or higher than it would be in any adjacent position of the body. An egg standing on its end, or a stick balanced upright on the finger, is in this state (fig. 26). As soon as the stick is out of the vertical its centre of gravity descends, and gravitation acting with increasing force, the stick falls, if care be not taken to bring the point of support below the centre of gravity, by which equilibrium is restored.

Neutral equilibrium. A body is in a state of neutral equilibrium

when it remains at rest in any position which can be given to it. This can only be the case when an alteration in the position of the

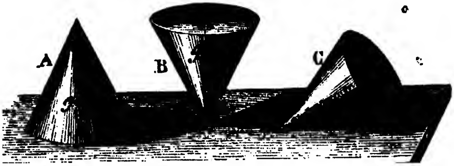


Fig. 30.

body neither raises nor lowers its centre of gravity. A perfect sphere resting on a horizontal plane is in this state.

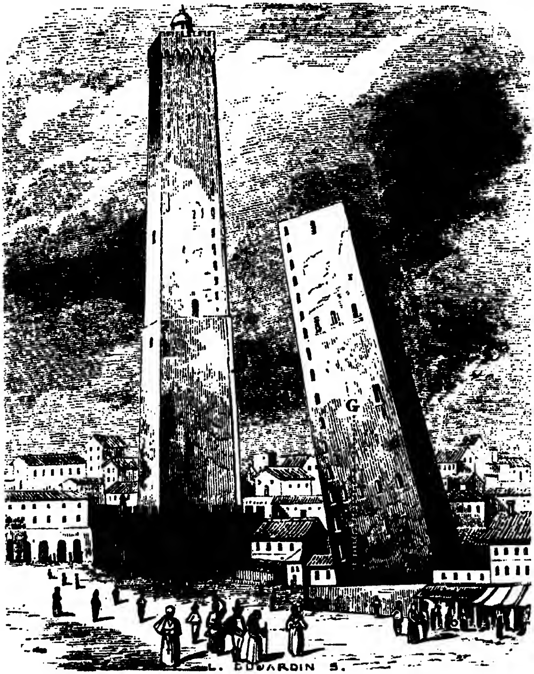


Fig. 31.

Fig. 31 represents three cones A, B, C, placed respectively in

stable, unstable, and neutral equilibrium upon a horizontal plane. The letter g in each shows the position of the centre of gravity.

46. **Examples of stable equilibrium.**—From what has been said it follows, that the wider the base on which a body rests the greater is its stability; for then, even with a considerable inclination, its centre of gravity is above its base.

The well-known leaning towers of Pisa and Bologna are so much out of the vertical that they seem ready to fall any moment; and yet they have remained for centuries in their present position, because their centres of gravity are above the base. Fig. 31 represents the tower of Bologna, built in the year 1112, and known as the *Garisenda.* Its height is 165 feet, and it is 7 or 8 feet out of the vertical. The leaning is due to the foundations having given way. The tower on the side is that of Asarelli, the highest in Italy.

In the cases we have hitherto considered the position of the centre of gravity is fixed: this is not the case with men and animals, whose centre of gravity is continually varying with their attitudes, and with the loads they support.

When a man, not carrying anything, stands upright, his centre of gravity is about the middle of the lower part of the pelvis, that is, between the two thigh bones. This, however, is not the case with a man carrying a load, for his own weight being added to that of the load, the common centre of gravity is neither that of the man nor of his burden.

Fig. 32.

Fig. 33.

In this case, in order to retain his stability, the man must so modify his attitude as to keep his centre of gravity above the base

formed by his two feet. Thus a porter with a load on his back is obliged to lean forward (fig. 32), while a man carrying a load in one hand is obliged to lean his body on the opposite side (fig. 33).

Again, it is impossible to stand on one leg if we keep one side of the foot and head close to a vertical wall, because the latter prevents us from throwing the body's centre of gravity vertically above the supporting base.

In the art of rope-dancing the difficulty consists in maintaining

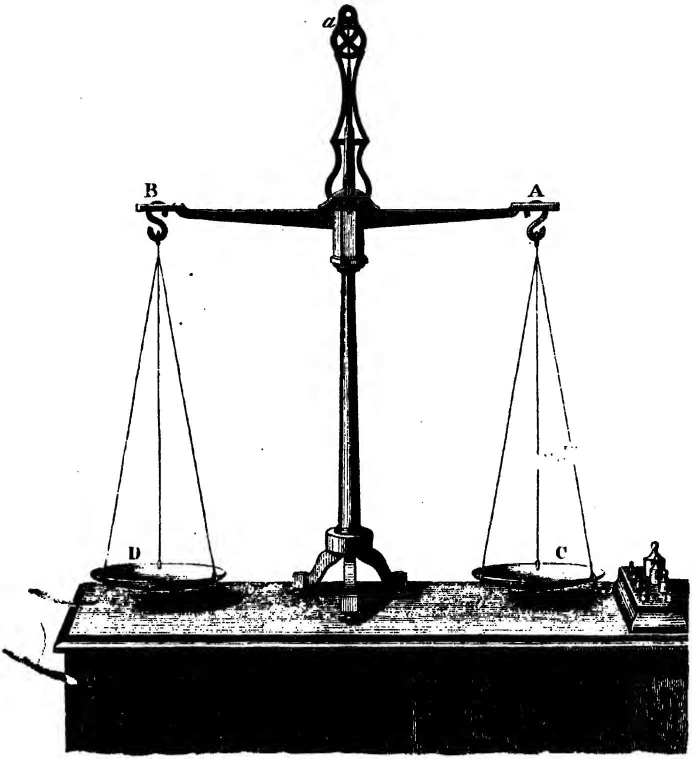


Fig. 34.

the centre of gravity exactly above the rope. In order more easily to accomplish this the performer holds in his hands a long pole,

which, as soon as he feels himself leaning on one side he inclines towards the opposite one; and thus contrives to keep the centre of gravity common to himself and the pole, above the rope, and so preserves his equilibrium.

47. **The balance.**—The balance is an instrument for determining the relative weights or masses of bodies. There are many varieties.

The ordinary balance (fig. 34) consists of a lever of the first kind, called the *beam*, with its fulcrum in the middle; at the extremities of the beam are suspended two *scale pans*, D and C; one intended to receive the object to be weighed, and the other the counterpoise. The fulcrum consists of a steel prism, *n*, commonly called a *knife edge*, which passes through the beam, and rests with its sharp edge, or *axis of suspension*, upon two supports; these are formed of agate, or polished steel, in order to diminish the friction. A needle or pointer is fixed to the beam, and oscillates with it in front of a graduated arc, *a*; when the beam is perfectly horizontal the needle points to the zero of the graduated arc.

Since (33) two equal forces in a lever of the first kind cannot be in equilibrium unless their leverages are equal, the length of the arms *n*A and *n*B ought to remain equal during the process of weighing. To secure this the scales are suspended from hooks, whose curved parts have sharp edges, and rest on similar edges at the ends of the beam. In this manner the scales are supported on mere points, which remain unmoved during the oscillations of the beam. [illegible] mode of suspension is represented in the above figure.

The weight of any body is determined by placing it in one of the pans of the balance D, for instance, and adding weights to the other until equilibrium is established, which is the case when the beam is quite horizontal.

48. **Conditions to be satisfied by a good balance.**—A good balance should be *accurate*, that is, it should give exactly the weight of a body; it should also be *delicate*, that is, the beam should be inclined by a very small difference between the weights in the two scales.

Conditions of accuracy. i. *The two arms of the beam ought to be precisely equal*, otherwise, according to the principle of the lever (33), unequal weights will be required to produce equilibrium. To test whether the arms of the beam are equal, weights are placed in the two scales until the beam becomes horizontal; the contents of

the scales being then interchanged, the beam will remain horizontal if its arms are equal, but if not, it will descend on the side of the longer arm.

ii. *The balance ought to be in equilibrium when the scales are empty*, for otherwise unequal weights must be placed in the scales in order to produce equilibrium. It must be borne in mind, however, that the arms are not necessarily equal, even if the beam remains horizontal when the scales are empty; for this result might also be produced by giving to the longer arm the lighter scale.

iii. *The beam being horizontal, its centre of gravity ought to be in the same vertical line with the edge of the fulcrum, and a little below the latter.* For if the centre of gravity coincided with this line, the action of gravity on the beam would be null, and it would not oscillate. If the centre of gravity were above the edge of the fulcrum the beam would be in unstable equilibrium; while, if it is below the fulcrum, the weight of the beam is continually tending to bring it back to the horizontal position as soon as it diverges from it, and the balance oscillates with regularity.

Conditions of delicacy. 1. *The centre of gravity of the beam should be very near the knife edge*; for then, when the beam is inclined, its weight only acting upon a short arm of the lever, offers but little resistance to the excess of weight in one of the pans.

2. *The beam should be light*; for then the friction of the knife edge upon the supports is smaller the less the pressure. In order more effectually to diminish friction, the edges from which the beam and scales are suspended are made as sharp as possible, and the supports on which they rest are very hard.

3. Lastly, *the longer the beam the more delicate is the balance;* because the difference in the weights in the pans then acts upon a longer arm of the lever.

49. **Method of double weighing.**—Notwithstanding the inaccuracy of a balance, the true weight of a body may always be determined by it. To do so, the body to be weighed is placed in one scale, and shot or sand poured into the other until equilibrium is produced; the body is then replaced by known weights until equilibrium is re-established. The sum of these weights will necessarily be equal to the weight of the body, for, acting under precisely the same circumstances, both have produced precisely the same effect.

50. **Weighing machines.**—One of the forms of these instru-

ments, which are of frequent use in railway stations, coal yards, etc., for weighing heavy loads, is represented in fig. 35. It consists of a platform, A, on which the body to be weighed is placed,

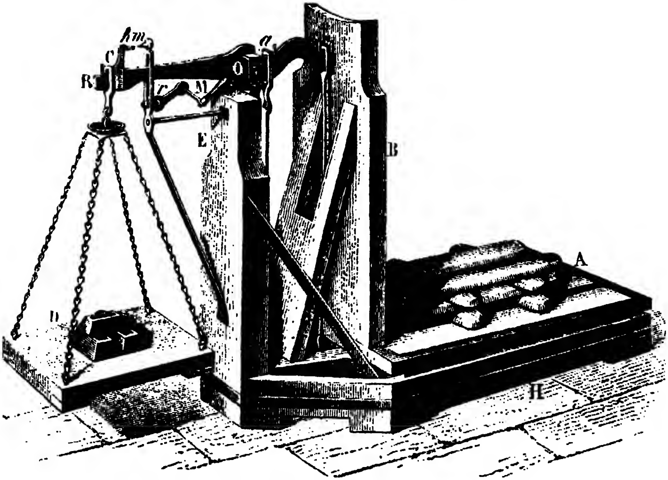


Fig. 35.

and to which an upright B is fixed; the whole rests on a frame, HE, by the following mode of suspension.

To the upright, E, are adapted two pieces of iron, which support a beam, LR, by the aid of a knife edge, which traverses it at O.

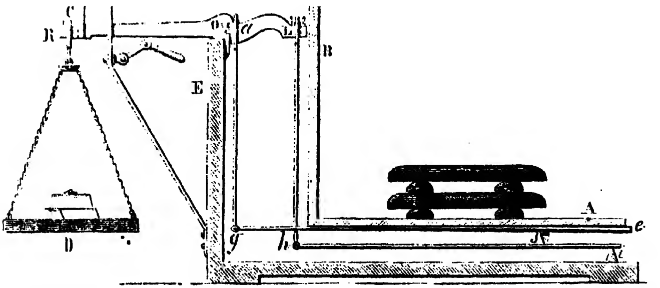


Fig. 36.

The two arms of the beam are unequal in length; one of them supports a scale, D, in which are placed the weights; the other arm

of the beam has two rods, by which is suspended the movable part, AB. In order to relieve the knife edge which supports the platform, and to avoid a shock when it is unloaded, after a weighing has been made, the arm, OR, is lifted by raising a support, *r*, which is below the beam, by means of the handle, M. The horizontality of the beam is ascertained by means of two indicators, *m* and *n*, the first fixed to the frame and the second to the beam.

To understand the working of the mechanism reference must be made to fig. 36, in which the principal pieces only are represented. A lever, *ih*, which bifurcates underneath the platform, rests at one end on a double knife edge, *i*, and at the other, on the lower end of the rod, L*h*, which is fixed to the beam. A second lever, *eg*, rests at *s* on the lever *ih*, attached at *g* to the rod *ag*, which is also supported by the beam. Lastly, the distance *is* being the fifth of *ih*, *a*O is also a fifth of OL.

From this division of the two levers, *ih* and OL, into proportional parts two important consequences follow. First, that when the beam oscillates, the points *a* and *g* being lowered by a certain amount, the points L and *h* are lowered five times as much. But for a similar reason, since the lever *ih* oscillates upon the knife edge *i*, the knife edge *s* is lowered one-fifth as much as the point, *h*, and therefore just as much as *g*. The lever *eg* therefore descends parallel to itself, and therefore also the platform A.

Secondly: it follows moreover, from the proportional division of the levers OL and *ih*, that the pressure at the points of suspension, exercised by the load *g* on the platform, is independent of the place which it occupies on the latter, so that it just acts as if it were applied along the rod *ag*. This may be deduced from the properties of the lever by a simple calculation, which cannot however be given here.

Lastly, since the weight is applied at *a*, the longer the arm of the lever OC as compared with O*a*, the smaller need be the weight in the scale D, in order to produce equilibrium. In most weighing machines O*a* is the tenth of OC. Hence the weights in the scale D represent one-tenth the weight of the body on the platform.

CHAPTER V.

LAWS OF FALLING BODIES. INCLINED PLANE. THE PENDULUM.

51. **Laws of falling bodies.**—When bodies fall in a vacuum—that is, when they experience no resistance—their fall is subject to the following laws :—

I. *In a vacuum all bodies fall with equal rapidity.*

II. *The space which a falling body traverses is proportional to the square of the time during which it has fallen*; that is, that if the space traversed in a second is 16 feet, in two seconds it will be 64 feet; that is, 4 times as much, and in 3 seconds 9 times as much, or 144 feet, and so on.

III. *The velocity acquired by a falling body is proportional to the duration of its fall*; that is, that if the velocity at the end of a second is 16 feet, at the end of two seconds it is twice 16, or 32 feet, at the end of 3 seconds 48 feet, and so forth.

Fig. 37.

To demonstrate the first law by experiment a glass tube about two yards long (fig. 37) may be taken, having one of its extremities completely closed, and a brass cock fixed to the other. After having introduced bodies of different weights and densities (pieces of lead, paper, feather, &c.) into the tube, the air is withdrawn from it by an air-pump, and the cock closed. If the tube be now suddenly reversed, all the bodies will fall equally quickly. On introducing a little air and again inverting the tube, the lighter bodies become slightly retarded, and this retardation increases with the quantity of air introduced.

It is, therefore, concluded that terrestrial attraction which is the cause to which the fall of bodies is due, is equally exerted on all substances, and that the difference in the velocity with which bodies fall is occasioned by the resistance of the air, which is more perceptible the smaller the mass of bodies and the greater the surface they present.

The resistance opposed by the air to falling bodies is especially remarkable in the case of liquids. The Staubbach in Switzerland is a good illustration; an immense mass of water is seen falling over a high precipice, but before reaching the bottom it is shattered by the air into the finest mist. In a vacuum, however, liquids fall like solids, without separation of their molecules. The *water hammer* illustrates this; the instrument consists of a thick glass tube about a foot long, half filled with water, the air having been expelled by ebullition previous to closing one extremity with the blow-pipe. When such a tube is suddenly inverted the water falls in one undivided mass against the other extremity of the tube, and produces a sharp dry sound, resembling that which accompanies the shock of two solid bodies.

The two other laws are verified by the aid of the inclined plane, and of Attwood's machine (fig. 40).

52. **Inclined plane.**—Any plane surface more or less oblique in

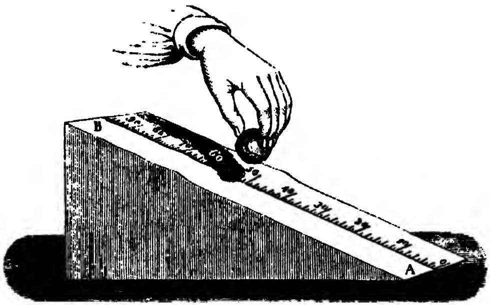


Fig. 38.

reference to the horizon is an *inclined plane.* Such is the surface (fig. 38), and also that of an ordinary desk.

When a body rests on a horizontal plane, the action of gravitation is entirely counteracted by the resistance of this plane. This, however, is not the case when it is placed upon an inclined plane;

the action of gravity is then decomposed into two forces (25), one perpendicular to the inclined plane, that is, acting along its surface, and the other parallel to the plane. The only effect of the first force is to press the first on the plane without imparting to it any motion ; while the second makes the body descend along the plane. This latter, however, is only one component of gravity; it is only a fraction, a third, or a quarter, according to the degree of inclination of the plane. Hence a body will roll down an inclined plane, but more slowly than if it fell vertically; and the velocity is indeed less the smaller the angle which the plane makes with the horizon.

53. **Demonstration of the second law of falling bodies by the inclined plane.**—The above property which the inclined plane possesses, of slackening the fall of bodies, has been used to demonstrate the second law of their fall (51), that *the space traversed by a falling body is proportional to the square of the time during which it has been falling.*

To make this experiment an inclined plane is taken, along which is traced a scale graduated in inches ; then taking a well-polished ivory ball, a position is found by trial, at which it just takes a second to reach the bottom of the inclined plane A. Let us suppose that this is at the eleventh division. The experiment is then repeated by making the ball traverse four times the distance, that is, placing it at the forty-fourth division, and it will then be found to take two seconds in so doing. In like manner it will be found that, in passing through nine times the distance, or through ninety-nine divisions, three seconds are required. Hence it is concluded, that the spaces traversed increase as the squares of the times.

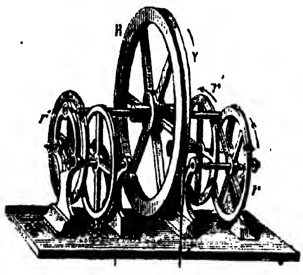
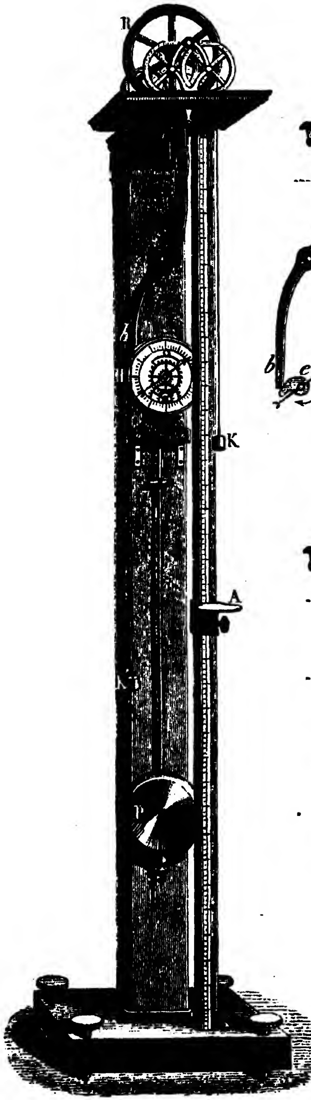


Fig. 39.

54. **Attwood's machine.** — Mr. Attwood invented a machine by which the velocity of falling bodies is slackened, and the laws of motion may be demonstrated. It consists of a wooden pillar about $2\frac{1}{2}$ yards high (fig. 40). On the front of the pillar is a clockwork motion, H, regulated in the usual way by a seconds' pendulum, P. On the right of the column is a graduated scale which measures the spaces traversed by the falling bodies. Along this scale two



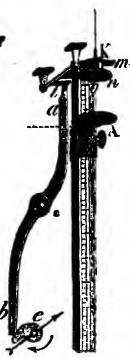


Fig. 41.

Fig. 42.

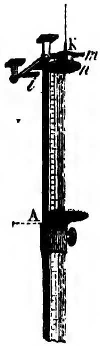


Fig. 43.

Fig. 44.

Fig. 45.

Fig. 46.

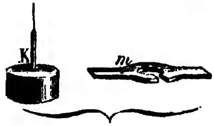


Fig. 47.

slides move, which can be fixed by a screw in any position; one of these has a disc, A, and the other a ring, B (fig. 44). At the top of the column is a brass pulley whose axis, instead of resting in pivots, turns on four other wheels, r, r, r', r', called *friction wheels*, since they serve to diminish friction (fig. 39). Two exactly equal weights, K and K', are attached to the end of a fine silk thread, which passes round the pulley.

At the top of the column is a plate, n, on which is placed the falling body (fig. 41). This plate is fixed to a horizontal axis which carries a small catch i, supported, when the plate is horizontal, by a lever, ab, movable in the middle. A spring placed behind the dial tends to keep this lever in the position represented in fig. 41, while an excentric, e, moved by the clockwork, tends to incline towards the right the upper arm of the lever ab. The parts are so arranged, that when the needle is at zero of the graduation, the lever ab is moved by the excentric; the plate n then lets fall the body which it sustained (fig. 42).

These details being premised we may add that the slackening which it produces in the fall of a body depends on the mechanical principle, that when a moving body meets another at rest it imparts to this latter a part of its velocity, which is greater the greater the mass of the second body compared with the first. For instance if a body with the mass 1, strikes against another at rest with the mass 19, the total mass being now 20, the common velocity after the impact is only a twentieth of the original velocity of the first.

First experiment. To demonstrate the second law, that *the spaces traversed are proportional to the squares of the times*, a weight K is placed upon the ledge n (fig. 41), and it is loaded with an over-weight, which consists of a brass disc, m (fig. 47), open at the side, so as to let pass a rod fixed to the weight K. Then below the ledge n the slider A is placed at such a distance that Km requires a second to traverse the space nA, which is easily obtained after a few trials. If the mass m fell alone it would traverse in a second about 32 feet; but from the principle stated above it can only fall by imparting to the masses K and K' what it carries with it, and hence its fall is the more diminished the smaller the mass m, as compared with the sum of the masses K and K'.

The experiment being prepared as indicated in fig. 41, the pendulum is made to oscillate; the clockwork then begins to move, and as soon as the needle arrives at zero the plate n drops (fig. 42), the weights K and m fall too, and the space nA is traversed in a second

by a uniformly accelerated motion. The experiment is recommenced, the slider A being placed at four times its original distance, that is, that if the distance A*n* were 8 inches (fig. 41) it is now 32 inches (fig. 43). But here when the plate *n* drops it is found that the weight K*m* requires exactly two seconds to traverse the space *An*. Increasing the space traversed to 72 inches, the time required for the purpose is found to be three seconds. That is, that when the times are twice or thrice as great, the spaces traversed are four, or nine times as great.

Second experiment.—To prove the law that *the velocities are proportional to the times*, the experiment is arranged as shown in figs. 44, 45, and 46, that is, the weights K and *m* being arranged as in the first experiment on the ledge *n*, at a distance of 8 inches below this the sliding ring B is placed, and at 16 inches below the disc A. When the ledge *n* has dropped, the weights K and *m* still require a second to fall from *n* to B. But then the over-weight *m* being arrested by the ring B (fig. 45), the weight K only falls in virtue of its acquired velocity. The motion which was uniformly accelerated from *o* to B (19) is kept uniform from B to A; for the weight *m* was the cause of the acceleration, and this having ceased to act, the acceleration ceases. It is then found that the space *o*B, equal to 8, having been traversed in one second, the space BA, equal to 16, is also traversed in a second. That is, 16 represents the velocity of the uniform motion, which, starting from the point B, has succeeded to the uniformly accelerated motion.

The experiment is finally recommenced by placing the sliding-ring B at the distance 32 (fig. 46), and sliding-disc below B, also at the distance 32. The space *o*B being then four times as great as in fig. 44 the weights K and *m* require, in accordance with the second law, twice the time. But the mass *m* being again arrested by the slider B, it is found that the weight K falls alone and uniformly from B to A in one second. The number 32 from B to A represents then the velocity acquired, starting from the point B after two seconds of fall. In the first part of the experiment it was ascertained that the velocity acquired after one second was 16; hence, in double the time, the velocity acquired is double. It may be shown, in like manner, that, after three times the time, the velocity is trebled, and so on; thus proving the third law.

55. **Pendulum.**—This is the name given to any heavy mass suspended by a thread to a fixed point, or to any metallic rod movable about a horizontal axis. The ball, *m*, suspended by the thread *cm*, which is fixed at the top at *c* (fig. 48), is a pendulum.

So long as the thread is vertical, which is the case when the centre of gravity of the ball is exactly below the point of suspension, *c*, the pendulum remains at rest, for the action of gravity is destroyed by the resistance at this point. This is no longer the case when the pendulum is removed from its vertical position; when it is placed, for instance, in the direction *cn* (fig. 49). The ball being raised, gravity tends to make it fall; it returns from *n* to *m*, and reaches the latter point with exactly the velocity it would have had by falling vertically through the height, *om*. The ball, accordingly, does not stop at *m*, but, in virtue of its inertia, and of its acquired velocity, it continues to move in the direction *mp*; as the ball rises, however, gravity, which had acted from *n* to *m* as an accelerating force, now exerts a retarding action, for it acts in a direction contrary to that of the motion; the motion, accordingly, becomes slower, and the ball stops at a distance, *mp*, which would

Fig. 48.

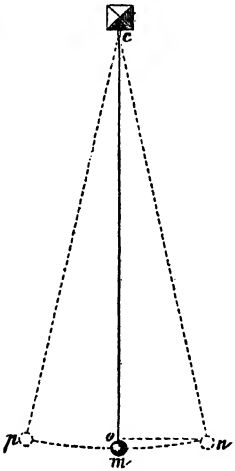


Fig. 49.

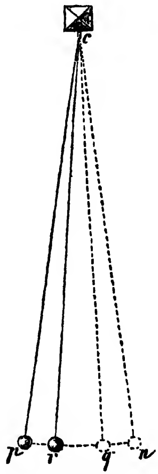


Fig. 50.

be exactly equal to *mn*, were it not for the resistance of the air, and also the rigidity of the thread, *cm*, which, as it is, offers a certain resistance to being bent about the point *c*, in passing from the position *cn* to *cp*, and *vice versâ*.

This being premised, the moment the ball stops at *p*, gravity acting so as to make it fall again, brings it from *p* to *m*, when,

owing to its inherent velocity, it rises virtually as far as n, and so on; a backward and forward motion is thus produced from n towards p, and from p towards n, which may last several hours.

This motion is described as an *oscillating motion.* The path of the ball from n to p, *or* from p to n, is known as a *semi-oscillation*, a *complete oscillation* being the motion from n to p, *and* from p to n. In France the former is known as a *single* oscillation, and the backward and forward motion as a *double* oscillation.

The *amplitude* of the oscillation is the distance between the extreme positions, cn and cp, and is measured by the arc, pn.

56. **Simple and compound pendulum.**—We distinguish in physics between the *simple* and the *compound* pendulum. The former would be that formed by a *single* material point, suspended by a thread *without* weight. Such a pendulum has only a theoretical existence; and it has only been assumed in order to arrive at the laws of the oscillations of the pendulum which we shall presently describe.

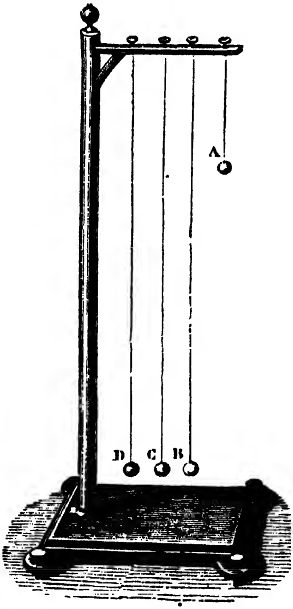


Fig. 51.

A *compound* or *physical pendulum* may be defined to be any body which can oscillate about a point or an axis. The pendulum described above (fig. 48) is of this kind. The form may be greatly varied, but the most ordinary one is a glass or steel rod (fig. 52) fixed at the top to a thin flexible steel plate, or to a knife edge like that of the balance (fig. 34). At the bottom of the rod is a heavy lens-shaped mass of metal, usually of brass, and known as the *bob*. The lenticular is preferred to the spherical form, for it presents less resistance to the air during each oscillation.

57. **Laws of the pendulum. Galileo.**—Whatever be the form of the pendulum, its oscillations always fall under the following laws. The first of these, that one and the same pendulum makes

its oscillations in equal times, was discovered by Galileo, the celebrated physicist and astronomer, at the end of the sixteenth century. It is related that he was led to this discovery, while still young, by observing the regular motion of a lamp suspended to the vault of the cathedral at Pisa. This property of the pendulum has received the name of *isochronism*, from two Greek words which mean equal times, and the oscillations are said to be *isochronous*.

First law; or, law of isochronism.—*The oscillations of one and the same pendulum are isochronous, that is, are effected in equal times.* This law is only perfectly exact for oscillations of small amplitude, four or five degrees at most; for a greater amplitude the oscillation is longer.

Second law; or, law of lengths.—With pendulums of different lengths *the duration of the oscillations is proportional to the square root of the length of the pendulum*; that is to say, that if the lengths of the pendulums are as 1, 4, 9, 16, the times of oscillations will be as 1, 2, 3, 4, these being the square roots of the former set of numbers.

Third law.—If the length of the pendulum remains the same, but the substances are different, *the duration of the oscillations is independent of the substance of which the pendulums are formed*; that is, that whether of wood, or of ivory, or of metal, they all oscillate in the same length of time.

Fourth law.—*The duration of the oscillations of a given pendulum is inversely as the square root of the force of gravity in the place in which the observation is made.*

58. **Verification of the laws of the pendulum.**—In order to verify the laws of the simple pendulum we are compelled to employ a compound one, the construction of which differs as little as possible from that of the former. For this purpose a small sphere of a very dense substance, such as lead or platinum, is suspended from a fixed point by means of a very fine thread. A pendulum thus formed oscillates almost like a simple pendulum, the length of which is equal to the distance of the centre of the sphere from the point of suspension.

In order to verify the isochronism of small oscillations, it is merely necessary to count the number of oscillations made in equal times, as the amplitudes of these oscillations diminish from *pn* to *rq* (fig. 50) say from three degrees to a fraction of a degree; this number is found to be constant.

That the time of vibration is proportional to the square root of

the length is verified by causing pendulums, whose lengths are as the numbers 1, 4, 9, ... to oscillate simultaneously. The corresponding numbers of oscillations in a given time are then found to be proportional to the fractions 1, $\frac{1}{2}$, $\frac{1}{3}$, etc. . . . . . , which shows that the times of oscillation increase as the numbers 1, 2, 3, ... etc.

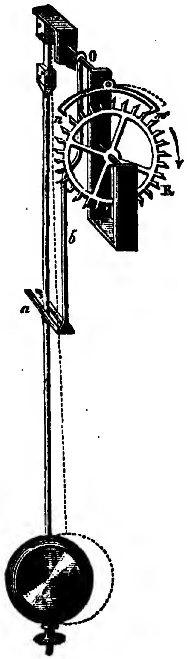


Fig. 52.

By taking several pendulums of exactly equal length B, C, D (fig. 51) but with spheres of different substances, lead, copper, ivory, it is found that, neglecting the resistance of the air, these pendulums oscillate in equal times, thereby showing that the accelerating effect of gravity on all bodies is the same at the same place.

59. **Measurement of the force of gravity.**—The relation which the fourth law of the pendulum establishes between the number of oscillations in a given time, and the force of gravity, is used to determine the magnitude of this force at different places on the globe. By counting the number of oscillations which one and the same pendulum makes in a given time, a minute, for example, in proceeding from the equator towards the poles, it has been found that this number continually increases, proving, therefore, that the force of gravity increases from the equator towards the poles.

By means of the pendulum the velocity has been calculated which a body acquires in falling, in a second of time, in vacuo, that is to say, when it experiences no resistance from the air. At London this is 32·19 feet.

Since the velocity which a body imparts to a movable body in a given time is greater in proportion as this force is more intense, the force of gravity in different places is measured by the velocity which it imparts to a body falling freely in a vacuum : in London, for instance, its intensity is 32·19 feet, at the equator, 32·09, and at Spitzbergen, 32·25 feet.

60. **Application of the pendulum to clocks.**—The regulation of the motion of clocks is effected by means of pendulums, that of

watches by balance-springs. Pendulums were first applied to this purpose by Huyghens in 1658, and in the same year Hooke applied a spiral spring to the balance of a watch. The manner of employing the pendulum is shown in fig. 52. The pendulum rod passing between the prongs of a fork, *a*, communicates its motion to a rod, *b*, which oscillates on a horizontal axis, *o*. To this axis is fixed a piece, *mn*, called an *escapement* or *crutch*, terminated by two projections or *pallets*, which work alternately with the teeth of the *escapement*

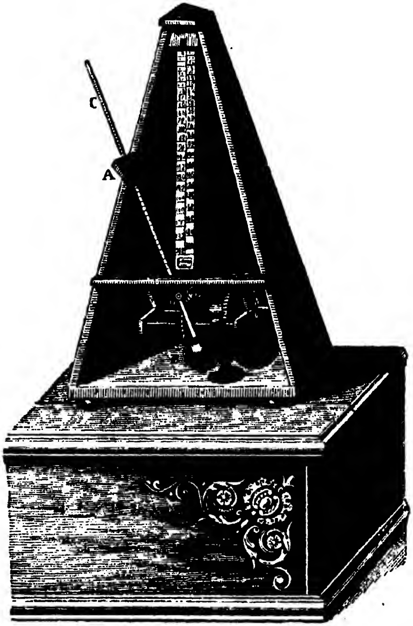


Fig. 53.

wheel, R. This wheel being acted on by the weight tends to move continuously, let us say, in the direction indicated by the arrow-head. Now if the pendulum is at rest, the wheel is held at rest by the pallet, *m*, and with it the whole of the clockwork and the weight. If, however, the pendulum moves and takes the position shown by the dotted line, *m* is raised, the wheel *escapes* from the confinement in which it was held by the pallet, the weight descends, and causes

the wheel to turn until its motion is arrested by the other pallet, *n*; which in consequence of the motion of the pendulum will be brought into contact with another tooth of the escapement wheel. In this manner the descent of the weight is alternately permitted and arrested—or, in a word, regulated—by the pendulum. By means of a proper train of wheelwork the motion of the escapement is communicated to the hands of the clock; and consequently their motion, too, is regulated by the pendulum.

Hence, to regulate a clock when it goes too slow or too fast, the length of the pendulum must be altered. If the clock goes too slow, it is because the pendulum oscillates too slowly, and it must therefore be shortened; if, on the contrary, it goes too fast, it must be lengthened. This shortening or lengthening is usually effected at the top of the pendulum by varying the length of the oscillating portion of the plate to which it is suspended. Clocks are provided with a simple arrangement for this purpose, which, however, is not represented in the figure.

61. **Metronome.**—This is another application of the isochronism of the oscillations of the pendulum, and is used to mark the time in practising music. As this time varies in different compositions, it is important to be able to vary the duration of the oscillations, which is effected as follows. The bob of the pendulum, B (fig. 53), is of lead, and it oscillates about an axis, *o*; the rod which is prolonged above this axis is provided with a weight, A, which slides on this axis and can be fixed in any position. This weight obviously acts in opposition to the oscillations of the bob, B, for when this tends to oscillate, for instance, from right to left, the weight tends to move the rod in the opposite direction, and this resistance which it affords to the motion is greater the longer the arm of the lever, A *o*, on which it acts. Hence the higher the weight, A, is raised, the slower are the oscillations. At the base of the instrument there is a clockwork motion, which works an escapement with such force that, at each oscillation of the pendulum, a tooth strikes strongly against a palette fixed to the axis, *o*, thus producing a regular beat which gives the time. In front of the box which contains the mechanism is a scale with numbers, indicating the height at which the weight must be placed to obtain a given number of oscillations in a minute. In the drawing this weight is at the number 92, which indicates that the pendulum makes 92 oscillations in a minute.

CHAPTER VI.

MOLECULAR ATTRACTION.

62. **Cohesion and chemical affinity.**—After having described, under the name of *universal gravitation*, the attraction which exists between the stars; and under that of *gravity*, the attraction which the earth exerts upon all bodies in making them fall towards it, we have to investigate the attractions which hold together the ultimate molecules of a body. These are—cohesion, affinity, and adhesion.

Cohesion is the force which unites two molecules of the same nature; for example, two molecules of water, or two molecules of iron. Cohesion is strongly exerted in solids, less strongly in liquids, and scarcely at all in gases. Its intensity decreases as the temperature increases, because then the repulsive force due to heat increases. Hence it is, that when solid bodies are heated they first liquefy, and are ultimately converted into the gaseous state, provided that heat produces in them no chemical change.

Cohesion varies not only with the nature of bodies, but also with the arrangement of their molecules; for example, the difference between tempered and untempered steel is due to a difference in the molecular arrangement produced by tempering. It is to the modifications which this force undergoes that many of the properties of bodies are due, such as tenacity, hardness, and ductility.

In large masses of liquids, the force of gravity overcomes that of cohesion. Hence liquids acted upon by the former force have no special shape; they take that of the vessel in which they are contained. But in smaller masses cohesion gets the upper hand, and liquids present then the spheroidal form. This is seen in the drops of dew on the leaves of plants; it is also seen when a liquid is placed on a solid which it does not moisten; as, for example, mercury upon wood. The experiment may also be made with water, by sprinkling upon the surface of the wood some light powder such as lycopodium or lampblack, and then dropping some water on it.

Chemical affinity is the force which is exerted between molecules not of the same kind. Thus, in water, which is composed of

oxygen and hydrogen, it is affinity which unites these elements, but it is cohesion which binds together two molecules of water. In compound bodies cohesion and affinity operate simultaneously, while in simple bodies cohesion has alone to be considered.

To affinity are due all the phenomena of combustion; when carbon burns it is affinity which causes this body to combine with the oxygen of the air to form the gas known as carbonic acid. It determines the combination of the elements, so that with a small number of them are formed the immense number of organic and mineral substances which serve for our daily uses.

The causes which tend to weaken cohesion are most favourable to affinity; for instance, the action of affinity between substances is facilitated by their division, and still more by reducing them to a liquid or gaseous state. It is most powerfully exerted by a body in its *nascent* state, that is, the state in which the body exists at the moment it is disengaged from a compound; the body is then free, and ready to obey the feeblest affinity. An increase of temperature modifies affinity differently under different circumstances. In some cases, by diminishing cohesion, and increasing the distance between the molecules, heat promotes combination. Sulphur and oxygen, which at the ordinary temperature are without action on each other, combine to form sulphurous acid when the temperature is raised. In other cases heat tends to decompose compounds by imparting to their elements an unequal expansibility; thus many metallic oxides, as for example those of silver and mercury, are decomposed, by the action of heat, into gas and metal.

63. **Adhesion.**—*Adhesion* is the name given to the attraction manifested by two bodies when their surfaces are placed in contact. If two leaden bullets are cut with a penknife so as to form two equal and brightly polished surfaces, and the two faces are turned against each other until they are in the closest contact, they adhere so strongly as to require a force of more than 3 or 4 ounces to separate them. The same experiment may be made with two equal pieces of glass, which are polished and made perfectly plane. When they are pressed one against the other, the adhesion is so powerful that they cannot be separated without breaking. As the experiment succeeds in vacuo, it cannot be due to atmospheric pressure, but must be attributed to a reciprocal action between the two surfaces. The attraction also increases as the contact is prolonged, and is greater in proportion as the contact is closer.

To adhesion is due the resistance experienced in raising a plank

placed on water; and to the same force is ascribed the difficulty met with in walking through thick mud. If we dip a glass rod into water, on withdrawing it a drop will be found to collect at the bottom, and remain suspended there. As the weight of the drop tends to detach it, there must necessarily be some force superior to this weight which maintains it there: this force is the force of adhesion.

The force of adhesion operates also between solids and gases. If a metal plate be immersed in water bubbles will be found to appear on the surface. As air cannot penetrate into the pores of the plate, the bubbles could not arise from air which had been expelled, but must be due to a layer of air which covered the plate and *moistened* it like a liquid.

CAPILLARITY. ABSORPTION.

64. **Capillary phenomena.**—When solid bodies are placed in contact with liquids, molecular attraction gives rise to a class of phenomena called *capillary phenomena*, because they are best seen in tubes whose diameters are comparable with the diameter of a hair. These phenomena are treated of in physics under the head of *capillarity* or *capillary attraction*: the latter expression is also applied to the force which produces the phenomena.

The phenomena of capillarity are very various, but may all be referred to the mutual attraction of the liquid molecules for each other, and to the attraction between these molecules and solid bodies. The following are some of these phenomena:—

i. When a glass rod is placed in a liquid which wets it, water for instance, the liquid, as if not subject to the laws of gravitation, is raised upwards against the sides of the solid, and its surface, instead of being horizontal, becomes slightly concave (fig. 54).

ii. If instead of a solid rod, a hollow tube be immersed in water (fig. 55), not merely is the liquid raised around the tube, but it rises in the inside to a height which is greater, the narrower the tube; and at the same time the surface of the liquid inside the tube assumes a concave form.

iii. If the tube is not moistened by the liquid, as is the case with mercury, the liquid is depressed instead of being raised, and the more so the narrower the tubes (fig. 56); and the surface, which was previously concave, now becomes convex. The surface of a liquid exhibits the same concavity or convexity against the sides of

a vessel in which it is contained, according as the sides are or are not moistened by the liquid.

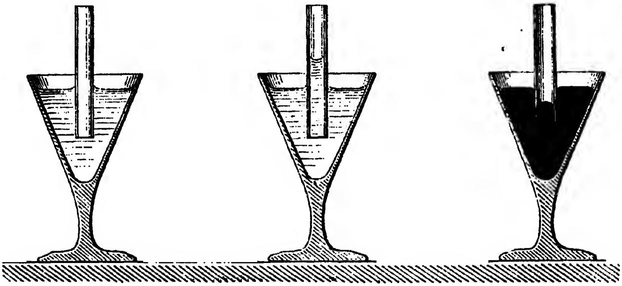


Fig. 54. Fig. 55. Fig. 56.

65. **Laws of capillarity.**—Gay-Lussac has shown experimentally that the elevation and depression of liquids in capillary tubes, the internal diameter of which does not exceed two millimeters, are governed by the following laws :—

I. *When a capillary tube is placed in a liquid, the liquid is raised or depressed according as it does or does not moisten the tube, and the elevation varies inversely as the diameter of the tube,* that is, it is two or three times as great when this diameter is two or three times as small.

II. *The elevation varies with the nature of the liquid, and with the temperature, but is independent of the nature and thickness of the tube.*

66. **Effects due to capillarity.**—It is from capillarity that sap rises in plants, that oil rises in the wicks of lamps, and melted tallow in the wicks of candles. The interstices which exist between the fibres of the cotton of which the wicks are formed, act as capillary tubes in which the ascent takes place. In very porous bodies, the pores being in communication with each other form a series of capillary tubes, which produces the same effect. If a lump of sugar be placed in a cup in which a little coffee is left, the liquid is seen to rise rapidly and fill the entire piece ; and it is even to be remarked that the sugar then dissolves more quickly than if it had been directly immersed in the coffee. This is due to the fact that in the latter case the air which fills the pores not being able to escape so rapidly as if the piece of sugar is only

partially immersed, prevents the liquid from penetrating into the mass of the sugar, and thus retards the solution.

Insects can often move on the surface of water without sinking. This is a capillary phenomenon caused by the fact, that as their feet are not wetted by the water, a depression is produced which keeps them up in spite of their weight. Similarly a sewing needle gently placed on water does not sink, because its surface, being covered with an oily layer, does not become wetted. But if previously washed in alcohol, or in potash, it at once sinks to the bottom.

67. **Absorption and imbibition.**—The words absorption and imbibition are used almost promiscuously in physics; they indicate the penetration of a liquid or a gas into a porous body. Absorption is used both for liquids and gases, while imbibition is restricted to liquids.

Charcoal has a great absorbing power for gases. If a piece of recently heated charcoal be passed into a bell jar full of carbonic acid placed over a mercury trough, the volume of gas is seen to diminish rapidly, and it is found that the gas which has disappeared, in penetrating the charcoal represents a volume thirty-five times that of the solid. There are even gases, such as ammonia, of which charcoal can absorb ninety times its own volume.

Absorption takes place in all parts of plants, but more especially in the rootlets and by the leaves. These organs absorb, in the form of water, carbonic acid, and ammonia, the oxygen, hydrogen, carbon, and nitrogen necessary for the growth of the plants.

Absorption also plays an important part both in the nutrition and respiration of animals. Animal tissues can even absorb solid substances. For instance, in those processes of the arts where the workmen have to handle salts of mercury or of lead, these metals are gradually absorbed into the system, and produce serious evils.

68. **Effects due to imbibition.**—Imbibition has been defined as being the penetration of a liquid into the pores of a solid body. It is a capillary effect, for the pores being in intercommunication act like small tubes; thus it is that water rises in wood, sponge, bibulous paper, sugar, sand, and in all bodies which possess pores of a perceptible size.

Owing to imbibition, tobacco soon dries if kept in a wooden box, while it remains fresh if kept in a metal one, for then its moisture is not absorbed by the metal as by the wood.

When water is absorbed by animal or vegetable matters their

volume increases. Thus if a tolerably large sheet of dry paper be measured and be then moistened, it will be found to have appreciably increased by this process. This property is made use of in stretching paper on drawing boards; the paper is moistened and is then glued or fastened with pins round the edge of the board. In drying the paper contracts, and is tightly stretched. For the same reason, too, wall papers which have been fastened on cloth along the walls, are frequently liable to be torn.

In bending wood, the side to be bent is heated, and the other side moistened. This being lengthened owing to the water it absorbs, while the other is contracted in consequence of the dryness, a curvature ensues on the heated side.

It is often observed that, owing to the changes of volume which they undergo under the influence of moisture and dryness, the furniture of our rooms is frequently heard to crack when the weather changes.

By the absorption of moisture ropes become shorter; and lengthen when they dry. This may seem opposed to what has been stated about moistened paper, but the explanation is not difficult. Ropes are formed of fibres twisted together, and as these fibres swell owing to the water they absorb, the rope becomes larger, and hence each fibre should make in coiling a longer circuit; and the rope will become more shortened the more it is moistened. For this reason, too, new cloths shrink considerably when they are moistened for the first time.

It is related that Pope Sixtus, wishing to raise in a place in Rome, an obelisk brought from Heliopolis to Rome under Caligula, for fear of disturbing the operation, ordered the spectators to preserve profound silence under pain of death. The obelisk was on the point of being placed on its pedestal, when the ropes began to stretch, owing to the great traction to which they were exposed, and the operation was in great danger. A voice from the crowd—that of the architect Zapaglia—cried out, 'Wet the ropes,' which was done, and the operation successfully performed.

CHAPTER VII.

PROPERTIES SPECIAL TO SOLIDS.

69. **Tenacity.**—Besides the general properties which we have hitherto been considering, and which are met with in solids, liquids, and gases, there are some special to solids which deserve mention, on account of the numerous applications which they present. They are—tenacity, hardness, ductility, and malleability.

Tenacity is the resistance which bodies oppose to being broken, when subjected to a greater or less traction. The tenacity of any particular body is determined by giving to it the form of a cylindrical or prismatic rod, one end of which is then firmly fixed in a vertical position to a support. To the lower end is fixed a scale-pan, in which weights are successively added until the rod breaks. The breaking weight represents the limit of the tenacity of a rod for a given section.

Of all substances iron has the greatest tenacity. A cylindrical iron rod with a section of a square centimeter, only breaks with a weight of 13,200 pounds. A rod of boxwood of the same dimensions, breaks with a weight of 2,640, and one of oak with 1,540 pounds; a steel wire supports a load of 39,000 times its own length; laths constructed of fine iron wire, the $\frac{1}{25}$ to $\frac{1}{30}$th of an inch in diameter, can support a load of 60 tons for each square inch of section.

Tenacity is directly proportional to the breaking weight, and inversely proportional to the area of a transverse section of the wire.

Tenacity diminishes with the duration of the traction. A small force continuously applied for a long time will often break a wire, which would not at once be broken by a larger weight.

Not only does tenacity vary with different substances, but it also varies with the form of the body. Thus, with the same sectional area, a cylinder has greater tenacity than a prism. The quantity of matter being the same, a hollow cylinder has greater tenacity than a solid one.

The shape has also the same influence on the resistance to crushing, as it has on the resistance to traction. A hollow cylinder with the same mass, and the same weight, offers a greater

resistance than the solid cylinder. It is for this reason that the bones of animals, the feathers of birds, the stems of corn and other plants, offer greater resistance than if they were solid, the mass remaining the same.

70. **Hardness**—*Hardness* is the resistance which bodies offer to being scratched or worn by others. It is only a relative property, for a body which is hard in reference to one body may be soft in reference to others. The relative hardness of two bodies is ascertained by trying which of them will scratch the other. Diamond is the hardest of all bodies, for it scratches all, and is not scratched by any. The hardness of a body is expressed by referring it to a *scale of hardness*: that usually adopted is—

1. Talc	5. Apatite	8. Topaz
2. Rock salt	6. Felspar	9. Corundum
3. Calcspar	7. Quartz	10. Diamond
4. Fluorspar		

Thus the hardness of a body which would scratch felspar, but would be scratched by quartz, would be expressed by the number 6·5.

The pure metals are softer than their alloys. Hence it is that for jewellery and coinage, gold and silver, which are soft metals, are alloyed with copper to increase their hardness.

The hardness of a body has no relation to its resistance to compression. Glass and diamond are much harder than wood, but the latter offers far greater resistance to the blow of a hammer. Hard bodies are often used for polishing powders; for example, emery, pumice, and tripoli. Diamond, being the hardest of all bodies, can only be ground by means of its own powder.

71. **Ductility.**—*Ductility* is the property in virtue of which a great number of bodies change their forms by the action of traction or pressure.

Certain bodies, such as clay, wax, etc., are so ductile that they can be drawn out, flattened, modelled, between the fingers; others, such as the resins and glass, require the aid of heat. Glass is then so ductile that it can be drawn out into fine threads, which are flexible enough to be woven into cloth.

Several metals, such as gold, silver, copper, are ductile, even at ordinary temperatures, but require the use of powerful agents, such as the draw-plate or the rolling mill.

72. **Malleability.**—Malleability is that modification of ductility which is exhibited when metals are hammered. This property

greatly increases with the temperature; everyone knows, for instance, that iron is easily forged when hot, and not when cold.

Gold is very malleable even at the ordinary temperature. To make the extremely thin plates of gold, known as *gold leaf*, the gold is first pressed, by means of the rolling mill, into long plates from two to three centimeters in breadth, and about the $\frac{1}{25}$ of an inch in thickness. These plates are then beaten into small squares by means of a hammer; these are then cut and beaten again, and so on. By beating them directly, the operation could not long be continued, for the metal would be torn; hence the plates to be beaten must be placed between plates of a substance which, while thin, affords great resistance. Sheets of vellum and parchment are first used for this purpose, and afterwards *gold beater's skin.*

Leaves of gold are thus obtained, which are so thin, that 20,000 superposed are only an inch thick. Silver and copper may also be worked in the same manner. These leaves are used in the arts for gilding on wood, paper, and other materials.

The following is the usual order of the metals under the draw-plate, the rolling mill, and the hammer, arranged in reference to their decreasing ductility.

Draw-plate	Rolling mill	Hammer
Platinum	Gold	Lead
Silver	Silver	Tin
Iron	Copper	Gold
Copper	Tin	Zinc
Gold	Lead	Silver
Zinc	Zinc	Copper
Tin	Platinum	Platinum
Lead	Iron	Iron

The metals must be pure; if they are alloyed with other metals they are fragile, and have but little ductility.

BOOK II.

HYDROSTATICS.

CHAPTER I.

PRESSURES TRANSMITTED AND EXERTED BY LIQUIDS.

73. **Object of Hydrostatics.**—The science of *hydrostatics*, from two Greek words, signifying *equilibrium of water*, treats of the conditions of the equilibrium of liquids, and of the pressure they exert, whether within their own mass, or on the sides of the vessels in which they are contained.

74. **Special characteristics of liquids.**—The essential character of a liquid is the extreme mobility of its molecules, which are displaced by the slightest force. The fluidity of liquids is due to this property; it, however, is not perfect, there is always a sufficient adherence between the molecules to produce a greater or less viscosity.

Another essential property of liquids, and one by which they are distinguished from gases, is their almost entire incompressibility. We have already seen that their compressibility is so small, that for a long time they were regarded as being quite incompressible. It was not before 1823 that Oersted, a Swedish physicist, first proved in an exact manner that liquids are compressible. The apparatus he used for this purpose is called the *piezometer* (πιέζω, I compress, μέτρον, measure). By its means it has been found that a pressure of one atmosphere compresses distilled water by about the $\frac{1}{200,000}$ part of its volume; mercury by the same pressure only undergoes about a tenth as great a diminution, and ether about 2½ times as much.

Liquids are also porous, elastic, and impenetrable, like all other

bodies. The proofs of their porosity have been already given, their elasticity is a necessary consequence of their compressibility. Their impenetrability is manifested whenever a solid is immersed in water. For if a vessel be quite filled with water, and any solid body be placed in it which does not absorb the liquid, it will be observed that a volume of water flows over, which is exactly equal to that of the solid immersed.

75. **Equality of pressures. Pascal's law.**—Liquids have the following remarkable property, which is not possessed by solids. It is often called Pascal's law, for it was first enunciated by that distinguished geometrician.

Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces and in a direction at right angles to those surfaces.

To get a clearer idea of the truth of this principle, let us conceive a cylindrical vessel, in the sides of which are placed various cylindrical tubulures, all of the same size, and closed by movable pistons (fig. 57). The vessel being filled with water, or any other liquid, the moment any pressure is applied to the piston A, all the other pistons are pressed outwards, showing that the pressure is not merely transmitted downwards upon the piston D, but laterally upon the pistons E and F, and upwards upon the pistons B and C. If, instead of pressing on the piston A, the pressure be exerted upon B, the same effects are produced; the piston A is then forced upwards.

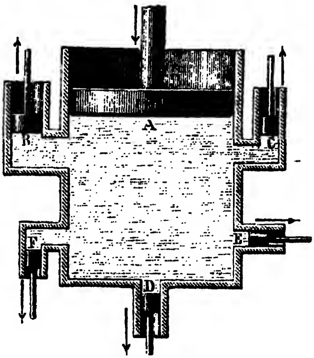


Fig. 57.

In these different cases, not only is the pressure transmitted in all directions, but for the *same surface* it is transmitted with the same intensity. For instance, if the pressure on the piston A is twenty pounds, and its surface is equal to that of the piston B, the upward pressure on the latter is also twenty pounds; but if the surface of the piston B is only a twentieth that of A, the pressure upon B is only one pound. This is the principle of *the equality of pressure.*

76. **Consequence and verification of Pascal's principle.**—It follows from what has been said, that *the pressure transmitted by a liquid is proportional to the extent of surface*; this is indeed only another enunciation of Pascal's principle.

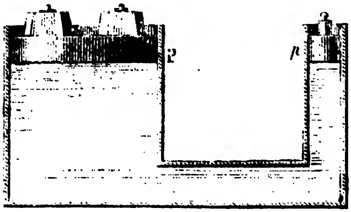


Fig. 58.

To verify this, two cylinders are taken of unequal dimensions, joined by a tube (fig. 58). These cylinders contain water, and are provided with pistons which move in them with gentle friction. Now if the surface of the larger one, P, for instance, is twenty times that of the smaller one, *p*, it will be found that a weight of a pound placed upon *p* will balance a weight of twenty placed upon P; if these weights are in any other ratio, equilibrium is destroyed.

The principle of the equality of pressures forms the basis of the whole science of hydrostatics, and we shall presently find a very important application of it, in the *hydraulic press* (82).

77. **Pressures resulting from the weights of liquids.**—In what has been said, we have considered the pressures transmitted towards the sides of the vessel, when some external force is applied. It is not, however, necessary thus to exert an external pressure on the surface of a liquid to produce internal pressures in its mass, and on the sides of the vessel. The mere weight of the liquid is sufficient to produce pressures which vary with the depth and the density of the liquid.

For suppose any vessel filled with liquid; if we conceive the liquid divided into horizontal layers of equal thickness, it is clear that the second layer supports a pressure equal to the weight of the first; that the third supports the weight of the first and second, and so on; so that the pressure increases with the number of layers, which is expressed by saying that gravity produces in liquids pressures proportional to the depth.

It is obvious moreover, that *these pressures are proportional to the density of the liquids*; that is, that for the same depth, a liquid which has two or three times the density of another, will exert twice or thrice as much pressure.

It follows from the principle of the equality of pressure in all directions, that the pressure produced by gravity in liquids is exerted

not merely in the direction of this force, but *horizontally*, and also *upwards*, as will now be demonstrated.

78. **Lateral pressures. Hydraulic tourniquet.**—The existence of lateral pressures which liquids exert upon the sides of the vessel in which they are contained, may be demonstrated by means of the *hydraulic tourniquet* or *Barker's mill* (fig. 59). This consists essentially of a long glass tube, C, with a funnel, D, at the top. The bottom of the tube fits into a hollow brass box, which rests on a pivot; in the sides of the box are fitted four brass tubes, arranged crosswise, and all bent in the same direction at the ends.

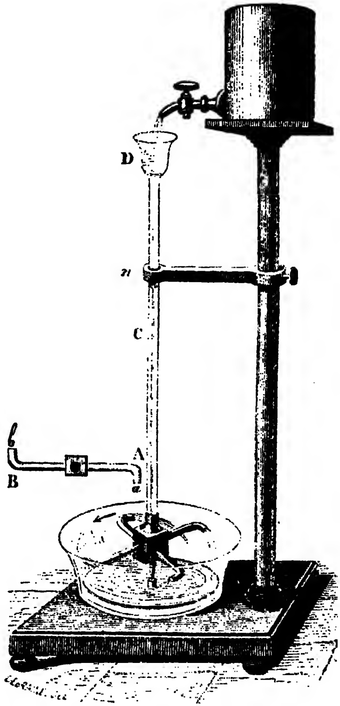


Fig. 59.

Water descending the long tube emerges by the apertures of the bent tubes, which are soon seen to rotate rapidly in the direction indicated by the arrow. This rotation is due to the lateral pressure exerted by the column of water in the long tube. For let us consider one of the bent tubes, *a*A, B*b*, represented in section on the left (fig. 59), and suppose first that the orifices, *a* and *b*, are closed. The column of water which then fills the tube C exerts upon the portions of the opposite sides, A and *a*, equal and contrary pressures which hold each other in equilibrium; this is also the case at B and *b*, and thus no rotation can be produced in either direction. But if the orifices *a* and *b* are open, as is the case when the apparatus is at work, as the water issues by these orifices, the pressures at *a* and *b* no longer exist; while those transmitted to A and B continuing to act, produce the rotation. Rotating fireworks also

act on the same principle as Barker's mill; that is, an unbalanced reaction from the heated gases which issue from openings in them gives them motion in the opposite directions.

It is owing to the lateral pressure of liquids that dykes and banks which retain rivers or reservoirs, sometimes give way, being too weak for the pressure they have to support.

79. **Vertical upward pressure.**—The pressure which the upper layers of a liquid exert on the lower layers causes them to exert an equal reaction in an upward direction, a necessary consequence of the principle of transmission of pressure in all directions.

The following experiment (fig. 60) serves to exhibit the upward pressure of liquids. A large open glass tube, one end of which is ground, is fitted with a ground glass disc, *a*, or still better, with a thin card or piece of mica, the weight of which may be neglected. To the disc is fitted a string, *b*, by which it can be held against the bottom of the tube. The whole is then immersed in water, and the disc does not fall, although no longer held by the string; it is consequently kept in its position by the upward pressure of the water. If water be now slowly poured into the tube, the disc will only sink when the height of the water inside the tube is equal to the height outside. It follows thence that the upward pressure on the disc is equal to the pressure of a column of water, the base of which is the internal section of the tube *a*, and the height the distance from the disc to the outer surface of the liquid. Hence *the upward pressure of liquids at any point is governed by the same laws as the downward pressure.*

Fig. 60.

This upward pressure is termed the *buoyancy* of liquids; it is perceived when the hand is plunged into water, and still more distinctly if it is immersed in mercury, which being of greater density produces greater pressure. It is owing to this buoyancy that, if a hole be made in the bottom of a ship, water enters with force.

80. **Pressure is independent of the form of the vessel.**—The pressure exerted by a liquid, in virtue of its weight, on any portion

of the liquid, or on the sides of the vessel in which it is contained, depends on the depth and density of the liquid, but *is independent of the form of vessel and of the quantity of the liquid.*

This principle, which follows from the law of the equality of pressure, may be experimentally demonstrated by many forms of apparatus. The following is the one most frequently used, and is due to Masson. It consists of a large conical vessel, M, screwed to a brass tubulure, *c*, fixed to a wooden support (fig. 61). This tubulure is closed by a disc, *a*, which does not adhere to it, but is

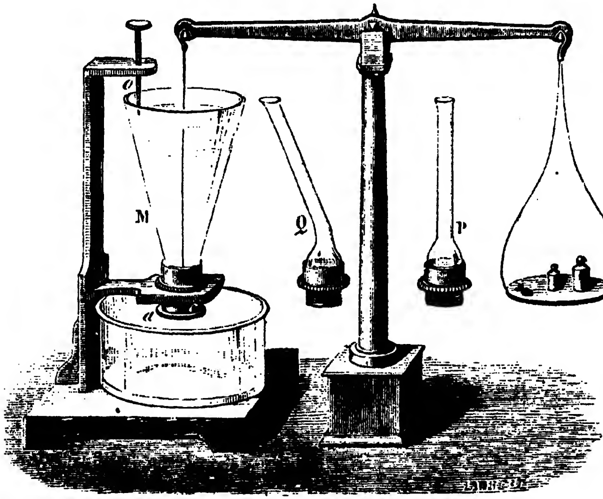


Fig. 61.

simply applied against the edge, and is kept there by a string attached to one end of an ordinary balance, to the other end of which is a scale-pan. Weights are placed in the latter, so as just to counterbalance the pressure of the water on the disc, when the vessel M is almost full; water is then gradually added until the disc just begins to give way and allows some to escape. A rod, *o*, is then lowered until its point just grazes the surface of the liquid. If the vessel M be unscrewed and replaced by the cylindrical tube, P, the capacity of which is far less, on gradually pouring water in, the moment the level of the liquid just touches the point of the rod, *o*, the disc, *a*, begins to allow some water to

escape. The same result ensues if for the straight tube, P, the inclined one, Q, be substituted. In these three cases, therefore, provided the height of the liquid is the same, the pressure is equal on the disc, *a*, whatever be the shape and capacity of the vessels.

Moreover, the weight which has to be put on the scale-pan to establish equilibrium, shows that *the pressure exerted by the liquid is equal to the weight of a column of water, the base of which is the internal section of the tubulure, c, and the height the vertical distance from the disc to the surface of the liquid.*

This principle is sometimes called the *hydrostatical paradox*, for at first sight it seems quite impossible.

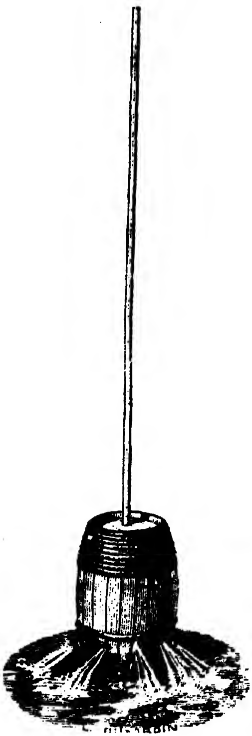


Fig. 62.

81. **Pascal's experiment.** — Pascal made the following experiment, which proves what great pressures may be produced by even small quantities of liquid when contained in vessels of great height. He fixed firmly, in a stout cask, as represented in fig. 62, a very narrow tube about 30 feet in height, and then filled the cask and the tube with water. The effect of this was to burst the cask; for there was a pressure on the bottom of the cask equal to the weight of a column of water whose base was the bottom itself, and whose height was equal to that of the water in the tube (80).

82. **Hydraulic press.**—The law of the equality of pressure has received a most important application in the *hydraulic press*, a machine by which enormous pressures may be produced. Its principle is due to Pascal, but it was first constructed by Bramah in 1796.

Fig. 63 represents an elevation, and fig. 64 a section of the instrument; it consists of two iron cylinders or barrels, A and B, of unequal diameters. In the barrel A, which is of very small diameter, is a cylindrical rod, *a*, which acts as piston, and can be moved up and down by the lever, O. In the cylinder, B, the internal diameter of which

is 12 to 15 times that of the barrel, A, is a long cylindrical iron ram, C, which also forms a piston, and works water-tight in the barrel B. On the top of the ram, C, is an iron slab, K, which

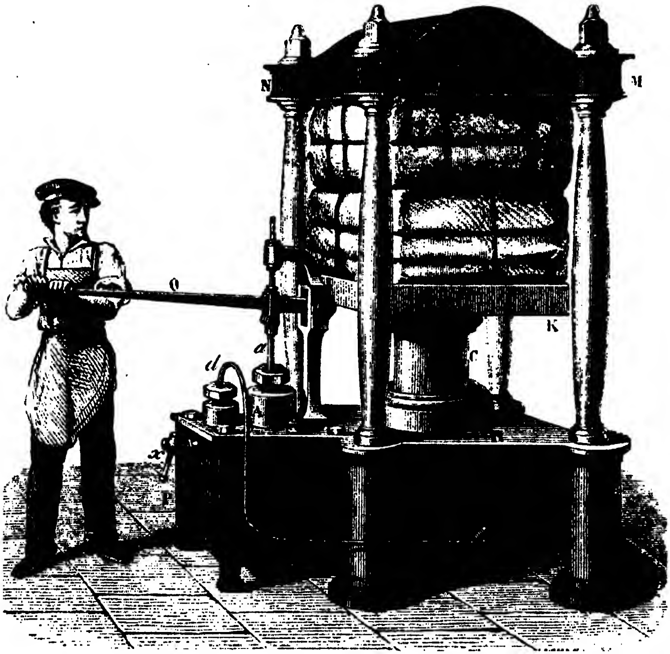


Fig. 63.

rises and falls with it. Four wrought-iron columns support a second plate, MN, which is fixed. The objects to be pressed are placed between K and MN.

When the piston is raised by means of the lever, a vacuum is produced in the barrel A, and a valve, S, at the bottom opens and allows water to pass from a reservoir, P, into the barrel. When *a* re-descends, the valve, S, closes; but another valve, *m*, placed at the bottom of the tube *d*, opens; the water is thus forced by this tube into the large cylinder, B. At the next stroke of the piston, *a*, a fresh quantity of water is drawn from the reservoir, P, and forced into the barrel B, and so forth.

In consequence of the principle of the equality of pressure, the downward pressure exerted by the small piston, *a*, is transmitted upwards upon the piston C. The pressure which can be obtained depends on the relation of the piston C to that of the piston *a*. If the former has a transverse section fifty or a hundred times as large as the latter, the upward pressure on the large piston will be fifty

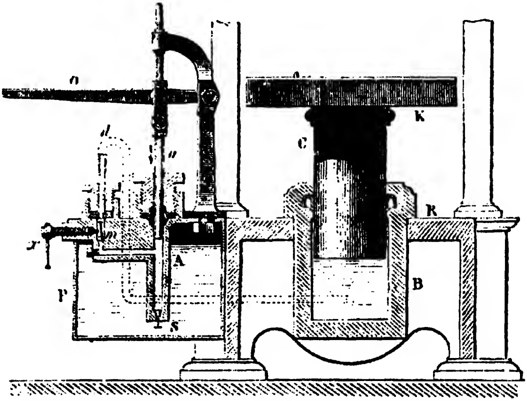


Fig. 64.

or a hundred times that exerted upon the small one. By means of the lever, O, an additional advantage is obtained. If the distance from the fulcrum to the point where the power is applied is five times the distance from the fulcrum to the piston, *a*, the pressure on *a* will be five times the power. Thus, if a man acts on O with a force of sixty pounds, the force transmitted by the piston *a* will be 300 pounds, and the force which tends to raise the piston C will be 30,000 pounds, supposing the section of C is a hundred times that of *a*.

The hydraulic press is used in all cases in which great pressures are required. It is used in pressing cloth, in extracting the juice of beet root, in expressing oil from seeds, and in pressing apples in making cider; it also serves to test the strength of cannon, of steam boilers, and of chain cables. The parts composing the tubular bridge which spans the Menai Straits were raised by means of an hydraulic press. The cylinder of this machine, the largest which has ever been constructed, was nine feet long and twenty-two inches in internal diameter; it was capable of raising a weight of two thousand tons.

CHAPTER II.

EQUILIBRIUM OF LIQUIDS.

83. **Conditions of the equilibrium of liquids.**—We have seen that the conditions of the equilibrium of a solid are that its centre of gravity be supported by a fixed point; all the other parts of the body then retain the same state of equilibrium in consequence of cohesion, which unites the particles together and to the centre of gravity. This is by no means the case with liquids: owing to the greater mobility of their molecules, and the facility with which they obey the force of gravity, they would flow away and spread out in a horizontal position, if they were not retained by some obstacle. Hence a liquid cannot be at rest in any vessel, unless it satisfies the following conditions:—

I. *The free surface of the liquid must be horizontal, that is, perpendicular everywhere to the direction of gravity.*

II. *Every molecule of the mass of the liquid must be subject in every direction to equal and contrary pressures.*

The second condition is self-evident; for if, in two opposite directions, the pressures exerted on any given molecule were not equal and contrary, the molecule would be moved in the direction of the greater pressure, and there would be no equilibrium. Thus the second condition follows from the principle of the equality of pressures; and from the reaction which all pressure causes on the mass of liquids.

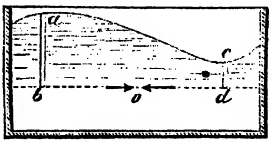


Fig. 65.

To account for the first condition relative to the free surface of the liquid, let us observe that in a liquid whose surface is horizontal, all the molecules supporting each other, the action of gravity is destroyed, and the liquid is at rest. But if the surface is not horizontal, if some parts are higher than others (fig. 65), the higher part, *ab*, exerts upon any horizontal layer, *bd*, a greater pressure than the part *cd*, and therefore as a given molecule, *o*, of the horizontal layer is exposed to a greater pressure in the direction *bo* than in the direction *do*, equilibrium is impossible.

In saying that in order that a liquid be at rest its surface must be horizontal, we must remark that that presumes the liquid only to be acted upon by gravity, which is usually the case; if it is under the action of other forces, as is the case with the capillary phenomena, where it is attracted by the sides of the vessel, its surface is then inclined so as to be perpendicular to the resultant of the forces which act upon it.

84. **Level of liquids.**—A liquid is said to be *level* when all the points of its surface are in the same horizontal plane. This, however, only applies to surfaces of small extent. For as the direction of the vertical constantly changes from one place to another on the surface of the globe, the direction of the horizontal surfaces changes too; that is to say, that a plane which is horizontal at one part of

Fig. 66.

the earth's surface, is not parallel to a horizontal plane at a small distance; they form an angle with each other. Hence a liquid surface of some extent in a state of equilibrium, being necessarily horizontal in each of its parts, does not form one single perfectly plane surface, but a series of plane surfaces inclined to each other; which of course produces a curved surface. This curvature cannot, however, be perceived on surfaces of small extent, as in water contained in a vessel; for the surface of such a liquid is so perfectly levelled, that it reflects the rays of light like the most per-

fectly polished plane mirror. The curvature is, however, easily observed on large surfaces like those of the sea. For if this surface were perfectly level, a ship in sailing away from the shore would only cease to be visible in consequence of increasing distance, and the less apparent parts, the masts and the cordage, would disappear first. This, however, is not the case ; the hull first sinks below the horizon, then the lower part of the masts, and ultimately the top, as seen in fig. 66, thus proving the curvature of the surface of the sea.

85. **True and apparent level.**—When we consider a great surface of water—the Mediterranean sea, for instance—its surface is said to be level when all points of the surface are equidistant from the centre of the earth. This is the *true level* ; while that level which is defined as having all the points of its surface in the same horizontal plane, is the *apparent level*, the level for the eye. The true only coincides with the apparent level when the liquid surfaces are very small. If the earth did not rotate about its own axis, the surface of all seas would form a true level ; but owing to the centrifugal force which results from its diurnal motion, the surface is heaped up at the equator, and the level is higher than at the poles.

86. **Equilibrium of the same liquid in several communicating vessels.**—Not merely do liquids tend to become level

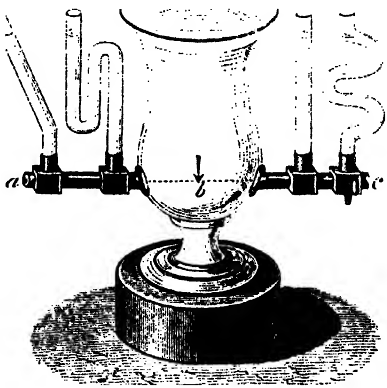


Fig. 67.

when they are placed in the same vessel, but also when they are placed in vessels which communicate with each other. Whatever

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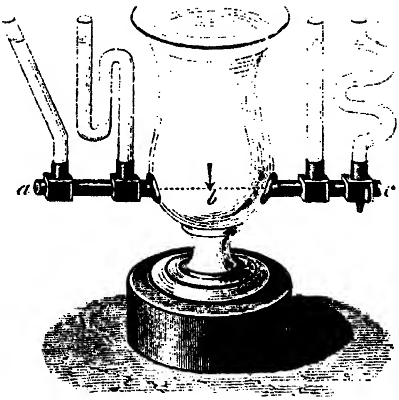

Fig. 67.

when they are placed in the same vessel, but also when they are placed in vessels which communicate with each other. Whatever

the shape and the dimensions of these vessels, equilibrium will exist, *when the surfaces of the liquids in all the vessels are in the same horizontal plane.*

This principle may be demonstrated by means of the apparatus represented in fig. 67. It consists of a series of vessels of different shapes and capacities connected together by a common horizontal tubulure. When water or any other liquid is poured into the vessel, the level is seen to rise at the same time, and stop at exactly the same height in each. Equilibrium is then established. For as we have seen that the pressures exerted by a liquid do not depend upon its quantity but upon its height (80), when this is the same for all the vessels above the tube of communication *abc*, the pressure is necessarily everywhere equal, and therefore, as the liquid has no more tendency to flow from *b* towards *a* than from *b* to *c*, equilibrium continues.

87. **Equilibrium of different liquids in communicating vessels.**—In what has been said the communicating vessels all

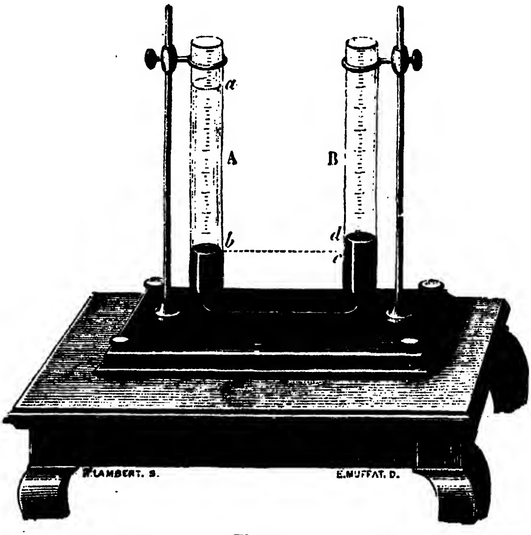

Fig. 68.

contained the same liquid. It may, however, happen that the vessels contain liquids of different densities, which do not mix.

The level is then no longer the same; the lighter liquids are higher, and equilibrium is only possible *when the heights of the liquid columns in communication are inversely as their densities*; that is, that if one of the liquids is twice or thrice as dense as another, its height will be half or one-third as much.

This principle is demonstrated experimentally by means of the apparatus represented in fig. 68. It consists of two glass tubes connected at the bottom by a narrow tube. The tubes are supported by two vertical columns, and on each of them is a scale graduated on the glass itself. If then mercury is poured into one of the tubes, it quickly assumes the same level in each. On now pouring water into the tube A, the level of the mercury is seen to sink in this tube in virtue of the pressure of the water, and it rises in the other tube. Then, when equilibrium is established, the mercury in B is higher than in the tube A by a quantity, *cd*. It is clear, then, that the pressure of the column of mercury, *cd*, counterbalances the pressure of the column of water, *ab*. If now the heights of *ab* and *cd* be measured by means of the graduated scales on the two tubes, it will be found that the height *cd* is 13·6 as small as that of *ab*; which demonstrates the above principle, for we shall presently see that mercury is 13·6 times as heavy as water.

88. **Equilibrium of superposed liquids.**—In order that there should be equilibrium when several heterogeneous liquids which do not mix are superposed in the same vessel, each of them must satisfy the conditions necessary for a single liquid; and further, *there will be stable equilibrium only when the liquids are arranged in the order of their decreasing densities from the bottom upwards.*

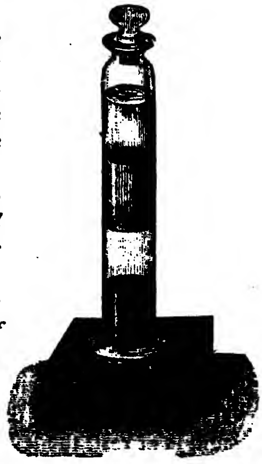

Fig. 69.

The last condition is experimentally demonstrated by means of the *phial of four elements* (fig. 69). It consists of a long narrow bottle containing mercury, water saturated with carbonate of potass, alcohol coloured red, and naphtha. When the phial is shaken the liquids mix, but when it is allowed to rest they separate; the mercury sinks to the bottom, then comes the water,

then the alcohol, and then the naphtha. This is the order of the decreasing densities of the bodies. The water is saturated with carbonate of potass to prevent its mixing with the alcohol.

This separation of the liquids is due to the same cause as that which enables solid bodies to float on the surface of a liquid of greater density than their own. It is also from this principle that fresh water, at the mouths of rivers, floats for a long time on the denser salt water of the sea; and it is for the same reason that cream, which is lighter than milk, rises to the surface.

APPLICATIONS OF THE PRINCIPLES OF THE EQUILIBRIUM OF LIQUIDS.

89. **Water level.**—In a great number of operations, such as the construction of canals, railways, roads, etc., it is continually necessary to determine the difference in level of two more or less distant places. The simplest apparatus for this purpose is the *water level*,

Fig. 70.

which is an application of the conditions of equilibrium in communicating vessels. It consists of a metal tube bent at both ends, in which are fitted glass tubes (fig. 70). It is placed on a tripod, and water poured in the tube until it rises in both limbs. When the liquid is at rest, the level of the water in both tubes is the same—that is, they are both in the same horizontal plane.

This instrument is used in levelling, or ascertaining how much one point is higher than another. If, for example, it is desired to

find the difference between the heights of two places, a *levelling-staff* is fixed on the latter place. This staff consists of a rule formed of two sliding pieces of wood, one of which supports a piece of tin plate, in the centre of which there is a mark. This staff being held vertically, an observer looks at it through the level along the surfaces in the two tubes, and directs the holder to raise or lower the slide until the mark is in the prolongation of the level in the two tubes. The assistant then reads off on the graduated rod the height of the mark above the ground. If this height exceeds that of the level, the height of the latter is subtracted from that of the former, and the difference gives the difference in the heights of the two places.

90. **Spirit level.**—The *spirit level* is both more delicate and more accurate than the water level. It consists of a glass tube (fig. 71), very slightly curved; it is filled with spirit with the ex-

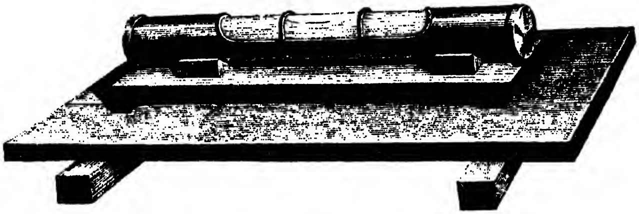

Fig. 71.

ception of a bubble of air, which tends to occupy the highest part. The tube is placed in a brass case, which is so arranged that when it is in a perfectly horizontal position the bubble of air is exactly between the two points marked in the case. But if the plane on which the instrument rests is ever so little inclined, the air bubble tends to move towards the higher part.

This thus furnishes a ready means of ascertaining whether any article—a table, a stand, or a bookshelf—is quite horizontal.

To take levels with this apparatus, it is fixed on a telescope, which can consequently be placed in a horizontal position.

91. **Jets of water.**—The jets which ornament our gardens and public places depend on the tendency of liquids always to become level. For the water which jets out always comes from a reservoir placed in a higher position than that where the jet is; and its jetting is a consequence of its tendency to form a level. Fig. 72 gives an idea of this phenomenon. On the eminence on the left of the figure is a reservoir containing water, from the bottom of which passes a

tube which terminates in the centre of the basin. The water then jets out, forced by the pressure of a column of water, the height of

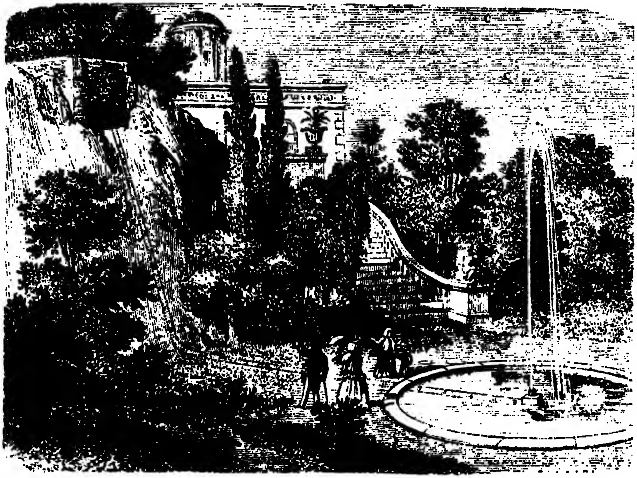

Fig. 72.

which is equal to the difference in level between the reservoir and the basin.

Theory proves that in such a case the water always tends to rise to the level of the reservoir from which it is supplied. It never attains this height, for the jet experiences three kinds of resistances: 1st, the friction of the water in the conduit pipe; 2nd, the resistance of the air; and 3rd, the hindrance offered by the particles falling from the height of the jet upon those ascending.

92. **Streams, springs, wells.**—The formation of springs upon the surface of the earth, and in its interior, is also due to the tendency of water to seek its level. For gravity causes water to flow from higher to lower places. Hence it is that the rain which falls upon the earth, and the water arising from the melting of snow, pass down to the valleys, where they form brooks, streams, and rivers, which flow along their beds as along an inclined plane, until they emerge into the seas. A very small fall can give rise to a current. Thus the mean height of the Seine at Paris is not more than 35 yards above the sea-level. The extent of its course between these two points is about 224 miles, which scarcely amounts to a fall of

the $\frac{1}{280}$th part of an inch in a yard; and water requires several days to traverse this distance.

All the rain which falls does not flow upon the surface; part of it penetrates into the earth, and gives rise to small subterranean watercourses, which are called *springs*. It is in order to procure water from these that *wells* are sunk.

93. **Artesian wells.**—When the spring which feeds a well comes from a place much higher than that where the well is sunk it may happen that water tends to rise higher than the ground. This is what happens in what are called *Artesian wells*. These wells derive their name from the province of Artois, where it has long been customary to dig them, and from whence their use in other parts of

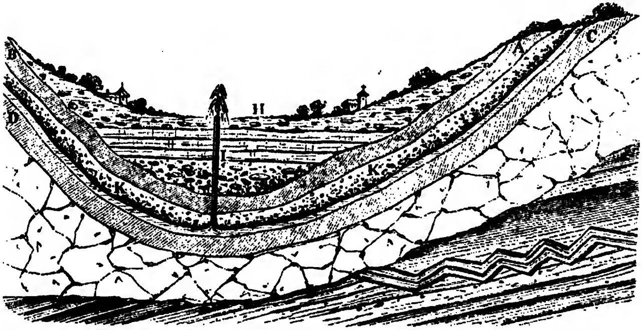

Fig. 73.

France and Europe was derived. It seems however, that at a very remote period, wells of the same kind were dug in China and Egypt.

To understand the theory of these wells, it must be premised that the strata composing the earth's crust are of two kinds: the one *permeable* to water, such as sand, gravel, etc.; the other *impermeable*, such as clay. Let us suppose, then, a geographical basin of greater or less extent, in which the two impermeable layers AB, CD (fig. 73), enclose between them a permeable layer KK. The rain-water falling on the part of this layer which comes to the surface, which is called the *outcrop*, will filter through it, and, following the natural fall of the ground, will collect in the hollow of the basin, whence it cannot escape, owing to the impermeable strata above and below it. If now a vertical hole, I, be sunk down to the water-bearing stratum, the water striving to regain its level will spout

out to a height which depends on the difference between the levels of the outcrop and of the point at which the perforation is made.

The waters which feed Artesian wells often come from a distance of sixty or seventy miles. The depth varies in different places. The well at Grenelle is 1,800 feet deep ; it gives 656 gallons of water in a minute, and is one of the deepest and most abundant which has been made. The temperature of the water is 27° C. It follows from the law of the increase of temperature with the increasing depth below the surface of the ground, that, if this well were 210 feet deeper, the water would have all the year round a temperature of 32° C., that is, the ordinary temperature of warm baths.

CHAPTER III.

PRESSURES SUPPORTED BY BODIES IMMERSED IN LIQUIDS. SPECIFIC GRAVITIES. AREOMETERS.

94. **Pressure supported by a body immersed in a liquid.**— When a solid is immersed in a liquid, it is obvious that the pressures which the sides of the vessel support are also exerted against the surface of the body immersed, since liquids transmit pressure in all directions (75). But it is readily seen that the pressures which the immersed body supports do not neutralise themselves, but have a resultant, the tendency of which is to move the body upwards.

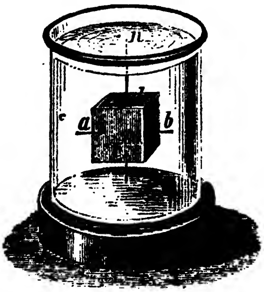

Fig. 74.

Let us imagine a cube immersed in a mass of water (fig. 74), and that four of its edges are vertical. The horizontal pressures upon the two opposite faces, *a* and *b*, are clearly of the same intensity, for they are exerted at the same depth (77); and as they are in opposite directions they will balance one another, and the only effect will be to compress the body without displacing it.

But the vertical pressures on the faces *d* and *c* are obviously unequal. The first is pressed downwards by a column of water whose

base is the face *d*, and whose height is *dn*, the lower face *c* is pressed upwards by the weight of a column of water whose base is the face itself, and whose height is *cn*. The cube, therefore, is urged upwards by a force equal to the difference between these two pressures, which latter is manifestly equal to the weight of a column of water having the same base and the same height as this cube. By this reasoning, therefore, we arrive at the remarkable principle, that *any body immersed in a liquid is pressed upwards by a pressure equal to the weight of the volume of liquid which it displaces.* We shall see how this principle can be experimentally verified.

95. **Principle of Archimedes. Hydrostatic balance.**—We have thus seen that any body immersed in a liquid is submitted to the action of two forces—gravity which tends to make it sink, and

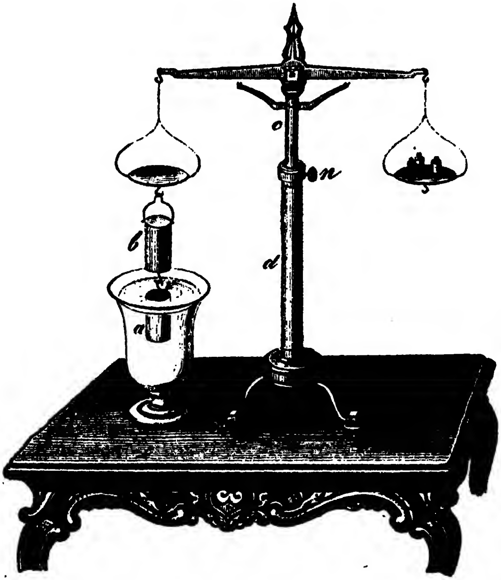

Fig. 75.

the buoyancy of the liquid which tends to raise it with a force equal to the weight of the liquid displaced. The body weighs less therefore than in air, and the diminution of its weight is exactly equal to the weight of the displaced liquid. The above principle may be

thus enunciated: that *a body immersed in a liquid loses a part of its weight equal to the weight of the displaced liquid.* For instance, suppose that a body which in air weighs 1,000 grains, when immersed in water displaces a cubic inch of water; it will now only weigh $1{,}000-252=748$ grains (a cubic inch of water $=252$ grains).

This principle, which is remarkable for its numerous applications, is called the 'principle of Archimedes,' after the discoverer. It is shown experimentally by means of the *hydrostatic balance* (fig. 75). This is an ordinary balance, each pan of which is provided with a hook; the rod, *c*, slides in the hollow cylinder, *d*. The beam is supported on the rod, *c*, which can be fixed in any position by means of a screw, *n*. The beam being raised, a hollow brass cylinder, *b*, is suspended to one of the pans, and below this a solid cylinder, *a*, whose volume is exactly equal to the capacity of the first cylinder; lastly, an equipoise is placed in the other pan. If now the hollow cylinder, *a*, be filled with water, the equilibrium is disturbed, but if at the same time the beam is lowered so that the solid cylinder becomes immersed in a vessel of water placed beneath it, the equilibrium will be restored. By being immersed in water, the cylinder *a* loses a part of its weight equal to that of the water in the cylinder *b*. Now as the capacity of the cylinder *a* is exactly the same as that of the cylinder *b*, the principle which has been laid down is proved.

It is stated that Archimedes discovered this principle on the occasion of a problem which had been propounded to him by Hiero, tyrant of Syracuse. This prince, desiring to offer to Jupiter a gold crown, had furnished a goldsmith with ten pounds of gold as the material for this purpose. The crown when finished was found to weigh ten pounds, but Hiero, suspecting that some of the gold had been replaced by silver, demanded from Archimedes a means of detecting the supposed fraud without destroying the crown, owing to the beauty of its workmanship.

Archimedes, pondering over the solution of the problem, was in the bath, when he observed that he could raise his limbs in water more easily than in air. This simple observation was a gleam of light for him; he discovered the above principle, and this led him to a simple means of calculating the quantity of gold and silver in the crown. It is said that Archimedes was so transported with joy at his discovery that he ran home from the bath, crying in the streets, Εὕρηκα, εὕρηκα (I have found it).

We have all had occasion to make the observation of Archimedes,

on observing how much lighter our limbs appear in water, and on the contrary, how much heavier they seem when lifted out. In like manner, if the body is almost entirely immersed in water, we can walk barefoot on the stones without injuring the feet; but this is not possible when we are out of the water. For in the former case part of the weight of the body is raised by the liquid, while in the latter the whole weight of the body presses the feet against the sharp projections.

96. **Equilibrium of immersed and floating bodies.**—When a body is placed in a liquid, three cases are possible: the body may have the same specific gravity as the liquid, in which case it weighs as much as the liquid for an equal volume; or it may be denser, in which case it weighs more; or it is lighter, and in this case it weighs less.

I. If the body immersed is of the same density as the liquid, the weight of the liquid displaced being the same as that of the body, it follows from Archimedes' principle, that the buoyancy which tends to raise it is exactly equal to the force with which gravity tends to sink it. The two forces are thus in equilibrium, and the body remains in suspension in any position in the liquid.

II. If the body immersed is denser than the liquid, it sinks, for then its weight preponderates over the buoyancy. This is the case when a stone or a mass of metal is thrown into water.

III. Lastly, if the immersed body is lighter than the liquid, the buoyancy prevails, and the body rises until it only displaces a weight of liquid equal to its own. It is then said to *float*. Cork, wax, wood, and all substances lighter than water, float on its surface.

A body which floats on one liquid may sink in another; the body for this purpose must be lighter than the one liquid, but heavier than the other. An egg sinks at once if placed in ordinary water, since it is heavier than an equal volume of water; but it swims if placed in strong brine, which is denser than water. A piece of oak floats on water, but sinks in oil, which is lighter than water. Iron floats on mercury, but sinks at once in water.

Yet a body, though denser than a liquid, may float on its surface. For this purpose it must have such a shape as to displace a volume of liquid, the weight of which is greater than its own. Porcelain is much heavier than water, yet a porcelain saucer placed on water floats on the surface; this arises from its concave shape, owing to which it displaces a weight of water equal to its own, though it is

only partially immersed. It is for the same reason that iron ships, even with very thick sides, float freely on water.

97. **Cartesian diver.**—The different effects of suspension, immersion, and floating are reproduced by means of a well-known hydrostatic toy, the *Cartesian diver* (fig. 76). It consists of a glass cylinder, nearly full of water, on the top of which a brass cap, A, provided with a piston, is hermetically fitted. In the liquid there is a little porcelain figure, a fish, *o*, for example, attached to a hollow glass ball, *m*, which contains air and water, and floats on the surface. In the lower part of this figure there is a little hole by which water can enter or escape, according as the air in the interior is more or less compressed. The quantity of water in the globe is such, that very little more is required to make it sink. If the piston be slightly lowered the air is compressed, and this pressure is transmitted to the water of the vessel and to the air in the bulb. The consequence is, that a small quantity of water penetrates into the bulb, which therefore becomes heavier and sinks. If the pressure is relieved, the air in the bulb expands, expels the excess of water which had entered it, and the apparatus being now lighter, rises to the surface. The experiment may also be made, by replacing the brass cap and piston by a cover of sheet india rubber, which is tightly tied over the mouth. When this is pressed by the hand the same effects are produced.

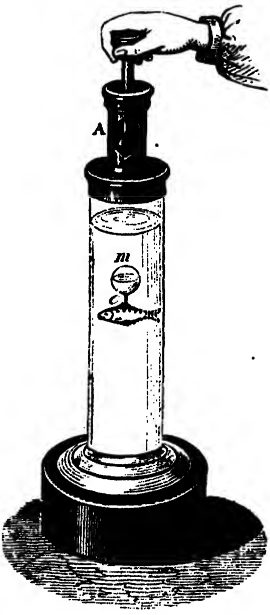

Fig. 76.

98. **Swimming bladder of fishes.**—Most fishes have an air-bladder below the spine, which is called the *swimming bladder.* The fish can compress or dilate this at pleasure by means of a muscular effort, and produce the same effects as those just described—that is, it can either rise or sink in water.

99. **Swimming.**—The human body is lighter, on the whole, than an equal volume of water; it consequently floats on the surface and still better in sea water, which is

heavier than fresh water. The difficulty in swimming consists, not so much in floating, as in keeping the head above water, so as to breathe freely. In man the head is heavier than the lower parts, and consequently tends to sink, and hence swimming is not natural to him, but is an art which requires to be learned. With quadrupeds, on the contrary, the head being less heavy than the posterior part of the body, remains above water without any effort, and these animals therefore swim naturally.

If a person who cannot swim, and who falls into the water, retains

Fig. 77.

coolness enough to turn on his back, so that his face is out of water, he can breathe freely, and wait until help arrives. Instead of this, however, he generally attempts to raise his arms out of water, as if grasping at some fixed support. This is very dangerous, for as the arms no longer displace a quantity of liquid equal to their own bulk, their weight is not diminished to that extent, but concurs with that of the head in making them sink.

Weight for weight, fat persons swim more easily than lean ones, for they displace more water. It is for the same reason that air bladders, or cork girdles, are fastened to persons who are learning to swim (fig. 77), for then, without any considerable increase of weight, they displace far more water, which increases the buoyancy and keeps them up.

Several kinds of birds, such as ducks, geese, and swans, swim easily on water. They owe this property to a thick coating of a light impervious down which covers the lower part of the body, so that they displace, even with a small immersion, a weight equal to their own.

SPECIFIC GRAVITIES. AREOMETERS.

100. **Specific gravities.**—Daily experience shows us that different substances have very unequal weights for one and the same volume. For instance, we all know that gold weighs more than silver, lead than iron, stones than wood. In order to compare equal volumes of various substances as to their weights, the weight of water has been taken as a standard of comparison—as *unity*. For water is everywhere met with, and can always be had pure; this latter condition is necessary, for the weight of a given quantity of water differs with the substances it holds in solution. As, moreover, the weight varies with the temperature, a constant temperature must be adopted. Hence the unit of weight is *distilled* water at a temperature of 4 degrees, for at this point, as we shall afterwards see, water has its greatest density.

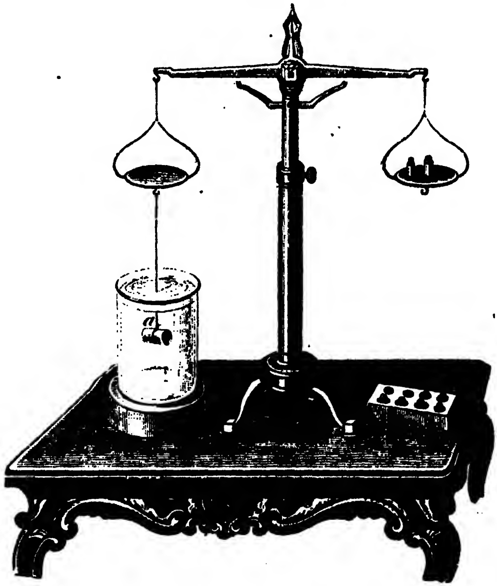

Fig. 78.

Thus having agreed to represent by 1 the weight of a certain volume of distilled water at 4 degrees, *the specific gravity* of a body

is the weight of *the same volume* of it as compared with that of water, or what is the same, the number which expresses how much it weighs as compared with water. Thus, when we say that the specific gravity of gold is 19, and that of lead 11, we mean that the former metal is 19 times, and the latter 11 times as heavy as water.

101. **Determination of the specific gravity of solids.**—Three methods are commonly used in determining the specific gravities of solids and liquids. These are—the method of the hydrostatic balance, that of the hydrometer, and that of the specific gravity flask. All three, however, depend on the same principle, that of first ascertaining the weight of a body, and then that of an equal volume of water. We shall first apply these methods to determining the specific gravity of solids, and then to the specific gravity of liquids.

i. *Hydrostatic balance.* To obtain the specific gravity of a solid, a piece of iron for instance, by the hydrostatic balance (fig. 78), it is first weighed in air by suspending it to the hook of one of the plates. Let us suppose that its weight is 585 grains. It is then weighed while immersed in distilled water, as shown in fig. 78. It will now weigh less; suppose the weight to be 510 grains, this is in accordance with Archimedes' principle, for it now loses a weight equal to that of the water it displaces. Hence, subtracting 510 from 585, the difference 75 represents the weight of the displaced water, that is, the weight of a volume of water equal to that of the iron: we need now only investigate how often the weight 75, that of the water, is contained in 585, that of the iron, and the quotient 7·8 is the specific gravity of iron; it says that, for equal volumes, this substance weighs 7·8 times as much as water.

Nicholson's hydrometer. This apparatus consists of a hollow metallic cylinder (fig. 79), to which is fixed a cone, *d*, loaded with lead. The object of the latter is to depress the centre of gravity so that the cylinder does not upset when in the water. At the top is a stem, *c*, terminated by a pan, *a*, in which is placed the substance whose specific gravity is to be determined. On the stem a standard point, *c*, is marked.

The apparatus stands partly out of the water, and the first step is to ascertain the weight which must be placed in the pan in order to make the hydrometer sink to the standard point *c* (fig. 80). Let this weight be 125 grains, and let sulphur be the substance whose specific gravity is to be determined. The weights are then removed from the pan, and replaced by a piece of sulphur which weighs less

than 125 grains, and weights added until the hydrometer is again depressed to the standard, *c*. If, for instance, it has been necessary

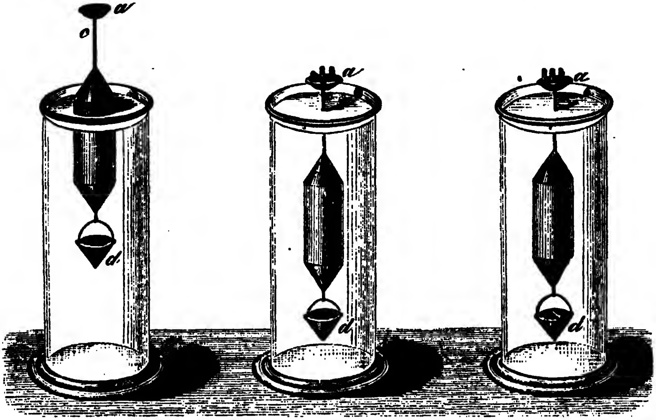

Fig. 79. Fig. 80. Fig. 81.

to add 55 grains, the weight of the sulphur is evidently the difference between 125 and 55 grains, that is, 70 grains.

Having thus determined the weight of the sulphur in air, it is now only necessary to ascertain the weight of an equal volume in water. To do this, the piece of sulphur is placed in the lower pan at *d*, as represented in fig. 81. The whole weight is not changed, nevertheless the hydrometer no longer sinks to the standard; the sulphur, by immersion, has lost a part of its weight equal to that of the water displaced. Weights are added to the upper pan until the hydrometer sinks again to the standard. This weight, 34·4 grains for example, represents the weight of the volume of water displaced; that is, of the volume of water equal to the volume of the sulphur. It is only necessary, therefore, to divide 70 grains, the weight in air, by 34·4 grains, and the quotient 2·03 is the specific gravity.

Specific gravity flask. In this method, which is advantageously used for the determination of the specific gravity of bodies in a state of powder, a wide-necked flask is used which can be carefully closed by a ground glass disc (fig. 82). Having filled it with water it is closed with the disc, great care being taken that not a bubble of air is left. After being carefully wiped dry, it is placed in the pan of a balance, and by its side is the substance, *a*, whose

specific gravity is to be determined. The whole is then equipoised by placing weights in the other pan of the balance. The substance, *a*, is then removed, and weights added in its place, until equilibrium is again established. The weight necessary for this purpose gives the weight of the substance in air.

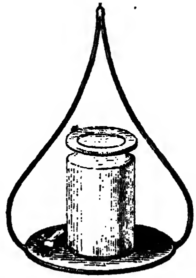

Fig. 82.

To obtain its weight in water it is placed in the flask, the disc adjusted, and the whole again carefully wiped. In order now to equipoise the tare in the second pan, weights must be added on the side of the flask to make up for the water displaced. The weights necessary for this purpose represent then the weight of a volume of water equal to that of the body.

Dividing, then, the weight of the body in air by the weight of an equal volume of water, we have the specific gravity sought.

102. **Specific gravity of liquids.**—These are determined by the same methods as those of solids.

Hydrostatic balance. In determining the specific gravity of a liquid by this means, a body is suspended to one of the pans of the balance, which is not dissolved by the liquid whose specific gravity is to be determined, nor in water; for instance, a ball of platinum, which is insoluble in all ordinary liquids. This ball is first weighed in air, then in water, and finally in the liquid in question, which we will suppose is alcohol. Let us assume that in air the ball weighs 510 grains, in water 486 grains, and in alcohol 489 grains. The loss of weight in water has thus been 510 less 486, or 24 grains, and in alcohol 510 less 499, or 21 grains; which tells us that if a volume of water equal to that of the ball weighs 24 grains, the same volume of alcohol weighs 21 grains. Hence, to obtain the specific weight of alcohol we must ascertain how many times the number 21 contains 24, which of course is obtained by division. The quotient thus obtained is 0·866, which represents the specific gravity of alcohol as compared with water.

ii. *Fahrenheit's hydrometer.* This instrument (fig. 83) resembles Nicholson's hydrometer, but is made of glass, so as to be used in all liquids. At its lower extremity, instead of a pan, it is loaded with a small bulb containing mercury. There is a standard mark on the stem, at the top of which is a pan.

The weight of the instrument is first accurately determined in air by means of an ordinary balance. Let us suppose that its weight

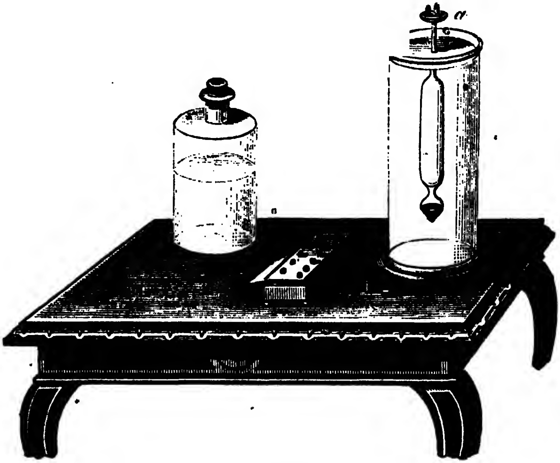

Fig. 83.

is 618 grains, and that the liquid whose specific gravity is to be determined, is olive oil. The hydrometer is placed in water, and the pan loaded with weights until the liquid is level with the mark on the stem. Suppose it has been necessary to add 93 grains for this purpose; these 93 grains, together with the 618 which the instrument weighs, make 711 grains, which represents the weight of water displaced by the instrument (96). The hydrometer is then removed, wiped dry, and immersed in the olive oil. Let us suppose that now only 31 grains need be added to sink the hydrometer to the mark. These, together with the 618 grains which the instrument weighs, in all 649, represent the weight of the displaced oil. We thus learn that equal volumes of oil and water weigh respectively 649 and 711. Hence we obtain the specific gravity of the latter as compared with the former by dividing 649 by 711. The quotient is 0·91, which teaches us that if a certain volume of water weighs 100 grammes, the same volume of oil weighs 91 grammes.

Neither Fahrenheit's nor Nicholson's hydrometers give such accurate results as the hydrostatic balance.

Specific gravity flask. This has been already described. In determining the specific gravity of a liquid, the flask is first weighed,

empty, and then, successively, full of water and of the given liquid. If the weight of the flask be subtracted from the two weights thus obtained, the result represents the weights of equal volumes of the liquid, and of water, from which the specific gravity is obtained by division.

Specific gravities of solids.

Platinum	22·069	Glass	2·48
Gold	19·36	Anthracite	1·80
Lead	11·35	Coal	1·32
Silver	10·47	Amber	1·07
Copper	8·87	Oak	0·84
Iron	7·78	Yellow pine	0·65
Zinc	6·86	Common poplar	0·38
Diamonds	3·53	Cork	0·24
Statuary marble	2·83		

Specific gravities of liquids.

Mercury	13·60	Claret	0·99
Sulphuric acid	1·84	Olive Oil	0·91
Milk	1·03	Oil of turpentine	0·87
Sea water	1·02	Absolute alcohol	0·80
Distilled water at 4° C.	1·00	Ether	0·72
Distilled water at 0° C.	0·99		

103. **Use of tables of specific gravities.**—Tables of specific gravity admit of numerous applications. In mineralogy the specific gravity of a mineral is often a highly distinctive character. Jewellers also use them. By means of tables of specific gravities the weight of a body may be calculated when its volume is known, and conversely the volume when its weight is known.

A knowledge of the specific gravity of a body furnishes also a simple means of calculating its volume when its weight is known, and conversely its weight when its volume is known.

With a view to explaining the last-mentioned use of these tables, it will be well to explain the connection existing between the British units of length, capacity, and weight. It will be sufficient for this purpose to define that which exists between the *yard*, *gallon*, and *pound avoirdupois*, since other measures stand to these in well-known relations. The yard, consisting of 36 inches, may be regarded as the primary unit. Though it is essentially an arbitrary standard, it is determined by this—that the simple pendulum which

makes one oscillation in a second, at London on the sea level, is 39·1375 inches long. The gallon contains 277·274 cubic inches. A gallon of distilled water at the standard temperature weighs 10 lbs. avoirdupois or 70,000 grains troy; or which comes to the same thing, one cubic inch of water weighs 252·5 grains.

On the French system the meter is the primary unit, and is so chosen that 10,000,000 meters are the length of a quadrant of the meridian from either pole to the equator. The meter contains 10 decimeters, or 100 centimeters, or 1,000 millimeters, its length equals 1·0936 yard. The unit of the measure of capacity is the litre or cubic decimeter. The unit of weight is the gramme, which is the weight of a cubic centimeter of distilled water at 4° C. The kilogramme contains 1,000 grammes, or is the weight of a decimeter of distilled water at 4° C. The gramme equals 15·443 grains.

Suppose it is required to calculate the weight of a cubic foot of coal. A cubic foot contains 1,728 cubic inches; the weight of a cubic foot of water would therefore be 1,728 times 252·5 grains, this being the weight of one cubic inch of water. The product of this multiplication divided by 7,000 grains (the number contained in a pound avoirdupois) gives 62.3 pounds as the weight of a cubic foot of water; and as we learn, from the tables, that coal is 1·32 times as heavy as water, the weight of a cubic foot of coal will be 1·32 times 62·3 or 83·16 pounds.

104. **Hydrometers with variable volume.**—The hydrometers of Nicholson and Fahrenheit are called *hydrometers of constant volume, but variable weight,* because they are always immersed to the same extent, but carry different weights. There are also *hydrometers of variable volume but of constant weight.* These instruments, known under the different names of *acidometer, alcoholometer, lactometer,* and *saccharometer,* are not used to determine the specific gravity of the liquids, but to show whether the acids, alcohols, solutions of sugar, etc., are more or less concentrated.

105. **Beaumé's hydrometer.**—This, which was the first of these instruments, may serve as a type of them. It consists of a glass tube, AB (fig. 84), loaded at its lower end with mercury, and with a bulb blown in the middle. The stem, the external diameter of which is as regular as possible, is hollow, and the scale is marked upon it.

The graduation of the instrument differs according as the liquid, for which it is to be used, is heavier or lighter than water. In the first case it is so constructed, that it sinks in water nearly to the

top of the stem, to a point A, which is marked zero. A solution of fifteen parts of salt in eighty-five parts of water is made, and the instrument immersed in it. It sinks to a certain point on the stem, B, which is marked 15; the distance between A and B is divided into 15 equal parts, and the graduation continued to the bottom of the stem. Sometimes the graduation is on a piece of paper in the interior of the stem.

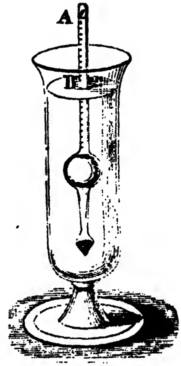

Fig. 84.

The hydrometer thus graduated only serves for liquids of a greater specific gravity than water, such as acids and saline solutions. For liquids lighter than water a different plan must be adopted. Beaumé took for zero the point to which the apparatus sank in a solution of 10 parts of salt in 90 of water, and for 10° he took the level in distilled water. This distance he divided into 10°, and continued the division to the top of the scale.

The graduation of these hydrometers is entirely arbitrary, and they give neither the densities of the liquids, nor the quantities dissolved. But they are very useful in making mixtures or solutions in given proportions; the results they give being sufficiently near in the majority of cases. For instance, it is found that a well-made syrup marks 35° on Beaumé's hydrometer, from which a manufacturer can readily judge whether a syrup which is being evaporated has reached the proper degree of concentration.

106. **Gay-Lussac's alcoholometer.**—The spirits of wine and brandy, in daily use, are a mixture of pure alcohol and water. The more alcohol they contain the stronger they are; the more water they contain so much the weaker are they. Hence it is important to have a simple means of exactly determining the quantity of water contained in spirituous liquors. This is effected by means of Gay-Lussac's *alcoholometer*, which has the same shape as Beaumé's, and only differs in the graduation. This is effected as follows :—

Mixtures of absolute alcohol and distilled water are made, containing 5, 10, 20, 30, etc., per cent. of the former. The alcoholometer is so constructed that when placed in pure distilled water, the bottom of its stem is level with the water, and this point is zero. It is next placed in absolute alcohol, which marks 100°, and then successively in mixtures of different strengths, containing 10, 20,

30, etc., per cent. The divisions thus obtained are not exactly equal, but their difference is not great, and they are subdivided into ten divisions, each of which marks *one* per cent. of absolute alcohol in a liquid. Thus a brandy in which the alcoholometer stood at 48, would contain 48 per cent. of absolute alcohol, and the rest would be water.

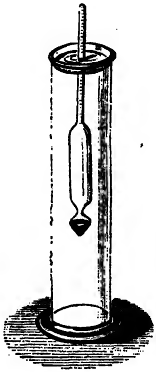

Fig. 85.

All these determinations are made at 15° C., and for that temperature only are the indications correct. For, other things being the same, if the temperature rises the liquid expands, and the alcoholometer will sink, and the contrary, if the temperature falls. To obviate this error Gay-Lussac constructed a table which for each percentage of alcohol gives the reading of the instrument for each degree of temperature from 0° up to 30°. When the exact analysis of an alcoholic mixture is to be made, the temperature of the liquid is first determined, and then the point to which the alcoholometer sinks in it. The number in the table corresponding to these data indicates the percentage of alcohol. From its giving the percentage of alcohol, this is often called the *centesimal alcoholometer.*

107. **Lactometer.** — The lactometer is a hydrometer like Beaumé's, specially graduated for the purpose of ascertaining the quality of milk (fig. 86). This is accomplished in the following manner :—The instrument is immersed in a vessel containing pure milk, and the point to which it sinks is marked zero on a paper strip affixed to the stem. Mixtures are then made of $\frac{9}{10}$ of milk and $\frac{1}{10}$ of water; of $\frac{8}{10}$ and $\frac{2}{10}$, and so on to $\frac{5}{10}$ of milk and $\frac{5}{10}$ of water. The lactometer is successively immersed in these, and sinks to different depths; the point at which it stops in each case is marked by a number on the stem, and thus indicates a milk of a particular strength, that is, one containing a certain quantity of admixed water.

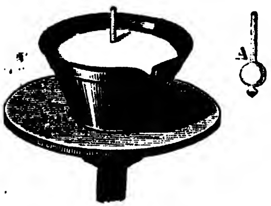

Fig. 86.

The lactometer is, however, no infallible test for the adulteration of milk; for the density of natural milk is subject to variation, and an apparent fraud may really be due to a bad natural quality of milk.

BOOK III.

ON GASES.

CHAPTER I.

PROPERTIES OF GASES. ATMOSPHERE. BAROMETERS.

108. **Physical properties of gases.**—Gases, as we have already seen, are bodies whose molecules are in a constant state of repulsion, in virtue of which they possess the most perfect mobility, and are continually tending to occupy a greater space. This property of gases is known by the names *expansibility*, *tension*, or *elastic force*, from which they are often called *elastic fluids*.

The number of gases of which chemistry teaches us is very considerable; but only four are elementary; these are oxygen, hydrogen, nitrogen, and chlorine. Some gases are coloured, but most of them are colourless. Some have a disagreeable odour, others are quite inodorous. Some are noxious, acting as poison to men and animals which breathe them: such are carbonic oxide, which is produced by the combustion of charcoal; sulphuretted hydrogen, which is given off from drains. Others are inoffensive, such as nitrogen and hydrogen; yet an animal cannot live in them. They are not deleterious, in the sense of being poisonous; but they do not support life. The only gas which has this property is oxygen; an animal deprived of this gas, even for a few seconds, soon dies.

Gases and liquids have several properties in common, and some in which they seem to differ are in reality only different degrees of the same property. Thus, in both, the particles are capable of moving; in gases quite freely; in liquids not quite freely, owing to a certain degree of viscosity. Both are compressible, though in very different degrees; if a liquid and a gas both exist under a pressure of one atmosphere, and then the pressure be doubled, the water is compressed by about the $\frac{1}{20000}$ part, while the gas is compressed by one-half. In density there is a great difference:

water, which is the type of liquids, is about 800 times as heavy as air, the type of gaseous bodies, while under a pressure of one atmosphere. The property by which gases are distinguished from liquids is their tendency to indefinite expansion.

Matter assumes the solid, liquid, or gaseous form according to the relative strength of the cohesive and repulsive forces exerted between their particles. In liquids these forces balance: in gases repulsion preponderates.

By the aid of pressure and of very low temperatures, the force of cohesion may be so far increased in many gases that they are converted into liquids, and there is reason for believing that, with sufficient pressure and cold, they might all be liquefied. On the other hand, heat, which increases the force of repulsion, converts liquids, such as water, alcohol, and ether, into the aëriform state in which they obey all the laws of gases. This aëriform state of liquids is known by the name of *vapour*, while gases are bodies which, under ordinary temperature and pressure, remain in the aëriform state.

In describing the properties of gases we shall, for obvious reasons, have exclusive reference to atmospheric air as their type.

109. **Atmospheric air.**—Air is the gaseous fluid in which we live. It was regarded by the ancients as one of the four elements. Modern chemistry, however, has shown that it is a mixture of oxygen and nitrogen gases in the proportion of 20·8 volumes of the former to 79·2 volumes of the latter. By weight it consists of 23 parts of oxygen to 77 parts of nitrogen.

The oxygen feeds all the combustions which are produced round about us; and it also supports animal life. If it alone were present, or even if it were present in a larger proportion, the combustions would be too brisk, and life too active. The coal of our fireplaces would burn almost instantaneously, and even the grates in which it is contained would take fire. Life would be promptly consumed by so active a principle. The function of the nitrogen is to attenuate the too powerful effects of the oxygen.

Air is inodorous, transparent, and colourless, at any rate in small masses. In larger masses it is blue; thus arises the blue colour of the sky. Without air the celestial vault would appear black; it appears almost so when viewed from the tops of very high mountains, and from balloons; for then the air above is very highly rarefied.

Air too, in virtue of its elasticity, is the medium for transmitting sounds; so that, if we were without it, the use of speech and of music would be lost.

110. **Expansibility of gases.**—This property of gases, their tendency to assume continually a greater volume, is exhibited by means of the following experiment. A bladder closed by a stopcock, moistened so as to render it more flexible, and about half full of air is placed under the receiver of the air pump (fig. 87), and a vacuum is produced on which the bladder immediately distends. This arises from the fact that the molecules of air repel each other and press against the sides of the bladder. Under ordinary conditions this internal pressure is counterbalanced by the air in the receiver, which exerts an equal and contrary pressure. But when this pressure is removed by exhausting the receiver, the internal pressure becomes evident. When air is admitted into the receiver the bladder resumes its original form. The same effects would be produced whatever gases were contained in the bladder, thus showing that all are expansible.

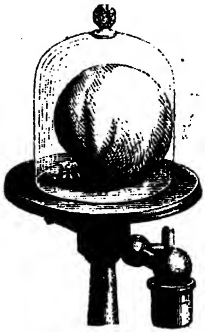

Fig. 87.

111. **Weight of gases.**—From their extreme fluidity and expansibility, gases seem to be uninfluenced by the force of gravity; they nevertheless possess weight, like solids and liquids. To show this, a glass globe of 3 or 4 quarts capacity is taken (fig. 88), the neck of which is provided with a stopcock, which hermetically closes it, and by which it can be screwed to the plate of the air pump. The globe is then exhausted, and its weight determined by means of a delicate balance. Air is now allowed to enter, and the globe again weighed. The weight in the second case will be found to be greater than before, and if the capacity of the vessel is known, the increase will obviously be the weight of that volume of air.

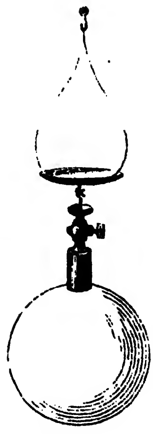

Fig. 88.

By a modification of this method, and with the adoption of certain precautions, the weight of air and of other gases has been determined: 100 cubic inches of dry air under the ordinary atmospheric pressure of 30 in. and at the temperature of 16° C., weigh 31 grains; the same volume of carbonic acid gas under the same circumstances

weighs 47·25 grains; 100 cubic inches of hydrogen, the lightest of all gases, weigh 2·14 grains; and 100 cubic inches of hydriodic acid gas weigh 146 grains.

The ratio of the density of air at 0° C. and 30 inches pressure to that of water at 0° C. is found to be 0·001296. In other words, the latter is 771 times as heavy as the former.

112. **The atmosphere. Experiments proving its weight.**—The *atmosphere* is the name given to the layer of air which, like a light coating, surrounds our globe in every part. It partakes of the rotatory motion of the globe, and would remain fixed relatively to terrestrial objects, but for local circumstances, which produce winds, and are constantly disturbing its equilibrium.

The existence of this gaseous mass is proved by the winds, which incessantly blow on the surface of the earth; by the flight of birds, and the suspension of clouds.

Besides the oxygen and nitrogen of which the air is composed, the atmosphere also contains a quantity of aqueous vapour, which varies with the temperature, the season, the locality, and the direction of the winds. The mean amount of this in London is from 5 to 6 grains in a cubic foot of air.

It further contains from 3 to 6 parts in 10,000 of carbonic acid. This arises from the respiration of man and animals, from the decay of organic matter, and from the combustion of wood and coal. This latter cause of the production of carbonic acid increases every year. It has been calculated that in Europe alone about 104 milliards of cubic yards of carbonic acid are every year sent into the atmosphere from this source. This mass of gas is equal to what would be produced by 509 millions of individuals, each converting by the act of respiration 154 grains of carbon in their system into carbonic acid every hour.

Notwithstanding this enormous continual production of carbonic acid on the surface of the globe, the composition of the atmosphere does not vary; for plants in the process of vegetation decompose the carbonic acid, assimilating the carbon, and restoring to the atmosphere the oxygen which is being continually consumed in the processes of respiration and combustion.

Thus, by a natural harmony, the atmosphere retains an almost uniform quantity of this gas, so that there is no fear of its accumulating to such an extent as to be injurious to the human species.

113. **Atmospheric pressure.**—Having seen that air has weight, it is easy to conceive that the great mass of air which constitutes

the atmosphere must exert a great pressure on the surface of the earth, and on all bodies found there. This pressure is called the *atmospheric pressure.* It necessarily decreases as we ascend in the atmosphere; for if we conceive the atmosphere resolved into horizontal layers superposed on each other, it is clear that the lower layers which support the weight of the whole atmosphere are the most compressed, and the most dense; while the higher layers are less and less compressed and therefore less and less dense. This is expressed by saying that they are more *rarefied* or more *rare.* In saying that 100 cubic inches of air weighed 31 grains, it was understood that air at the sea level was referred to; at any greater height this volume would weigh less.

The pressure of the atmosphere may be demonstrated by a number of experiments, among which are the following:

114. **Crushing force of the atmosphere.**—On one end of a stout glass cylinder, about 5 inches high, and open at both ends, a piece of bladder is tied quite air-tight. The other end, the edge of which is ground and well greased, is pressed on the plate of the air-pump (fig. 89). The bladder is pressed downwards by the weight of the atmosphere, and is pressed upwards by the expansive force of the air in the cylinder. These two pressures at first counterbalance

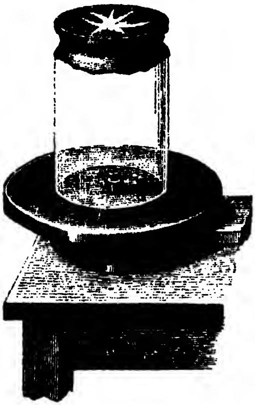

Fig. 89.

Fig. 90.

each other; the bladder is not pressed in either direction, but as soon as the internal air is removed from the vessel by working

the air pump, the bladder is depressed by the weight of the atmosphere above it, and finally bursts with a loud report caused by the sudden entrance of the air

115 **Magdeburg hemispheres** —The preceding experiment only serves to illustrate the downward pressure of the atmosphere By means of the *Magdeburg hemispheres* (fig 90), the invention of which is due to Otto von Guericke, burgomaster of Magdeburg, it can be shown that the pressure acts in all directions This apparatus consists of two hollow brass hemispheres of 4 to 4½ inches diameter, the edges of which are made to fit tightly, and are well greased One of the hemispheres is provided with a stopcock, by which it can be screwed on the air-pump, and on the other there is a handle As long as the hemispheres contain air they can be separated without any difficulty, for the external pressure of the atmosphere is counterbalanced by the elastic force of the air in

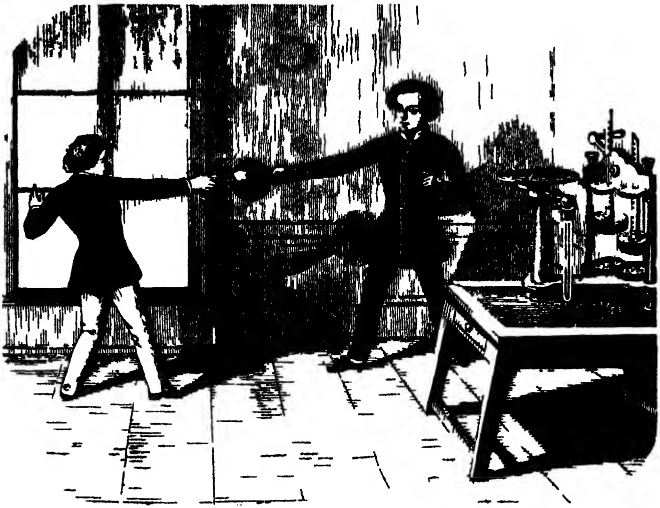

Fig 91

the interior But when the air in the interior is pumped out by means of the air pump, the hemispheres cannot be separated without a powerful effort, fig 91, and as this is the case in whatever position they are held, it follows that the atmospheric pressure is ransmitted in all directions.

We shall presently see that the pressure on the atmosphere on a square inch is 15 lbs. Hence if in the above experiment, the area, not of each of the hemispheres but of the circle along which they are pressed, is 10 square inches, the force by which they are pressed together is 150 lbs., and this force would be required to separate them.

It is related that Otto von Guericke, the inventor of this apparatus, constructed hemispheres the internal diameter of which was about 2 feet, when applied against each other and exhausted, twelve horses, six pulling at each hemisphere, were required for their separation.

DETERMINATION OF THE ATMOSPHERIC PRESSURE. BAROMETERS.

116. **Torricelli's experiment.**—The above experiments demonstrate the existence of the atmospheric pressure, but they give no indications as to its amount. The following experiment, which was first made in 1643 by Torricelli, a pupil of Galileo, not merely proves the pressure of the atmosphere, but also gives an exact measure of its weight.

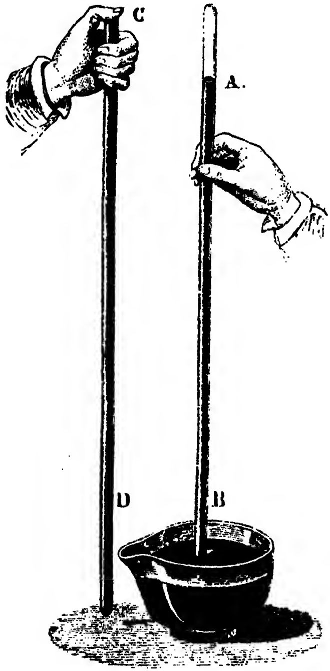

Fig. 92.

A glass tube is taken, about a yard long and a quarter of an inch internal diameter (fig. 92). It is sealed at one end, and is quite filled with mercury. The aperture C being closed by the thumb, the tube is inverted, the open end placed in a small mercury trough, and the thumb removed. The tube being in a vertical position, the column of mercury sinks, and after oscillating some time, it finally comes to rest at a height A, which at the level of the sea is about thirty inches above the mercury in

the trough. The mercury is raised in the tube by the pressure of the atmosphere on the mercury in the trough. There is no contrary pressure on the mercury in the tube, because it is closed. But if the end of the tube be opened, the atmosphere will press equally inside and outside the tube, and the mercury will sink to the level of that in the trough. It has been shown in hydrostatics (87) that the heights of two columns of liquid in communication with each other are inversely as their densities; and hence it follows, that the pressure of the atmosphere is equal to that of a column of mercury, the height of which is thirty inches. That the mercury sank in the first case was due to its weight being greater than the pressure of the atmosphere. If, however, the weight of the atmosphere diminishes, the height of the column which it can sustain must also diminish.

117. **Pascal's experiments.**—Pascal, who wished to prove that the force which sustained the mercury in the tube was really the pressure of the atmosphere, made the following experiments:—i. If it were the case, the column of mercury ought to descend in proportion as we ascend in the atmosphere. He accordingly requested one of his relations to repeat Torricelli's experiment on the summit of the Puy de Dôme in Auvergne. This was done, and it was found that the mercurial column was about three inches lower, thus proving that it is really the weight of the atmosphere which supports the mercury, since, when this weight diminishes, the height of the column also diminishes. ii. Pascal repeated Torricelli's experiment at Rouen, in 1646, with other liquids. He took a tube closed at one end, nearly 40 feet long, and having filled it with water, placed it vertically in a vessel of water, and found that the water stood in the tube at a height of 34 feet; that is, 13·6 times as high as mercury. But since mercury is 13·6 times as heavy as water, the weight of the column of water was exactly equal to that of the column of mercury in Torricelli's experiment, and it was consequently the same force, the pressure of the atmosphere, which successively supported the two liquids. Pascal's other experiments with oil and with wine gave similar results.

118. **Amount of the atmospheric pressure.**—Let us assume that the tube in the above experiment is a cylinder, the section of which is equal to a square inch, then, since the height of the mercurial column in round numbers is 30 inches, the column will contain 30 cubic inches, and as a cubic inch of mercury weighs 3433·5 grains = 0·49 of a pound, the pressure of such a column on a

square inch of surface is equal to 14·7 pounds. In round numbers the pressure of the atmosphere is taken at 15 pounds on the square inch. A surface of a foot square contains 144 square inches, and therefore the pressure upon it is equal to 2,160 pounds, or nearly a ton.

A gas or a liquid which acts in such a manner that a square inch of surface is exposed to a pressure, 15 pounds, is said to exert a pressure of *one atmosphere.* If, for instance, the elastic force of the steam of a boiler is so great that each square inch of the internal surface is exposed to a pressure of 90 pounds ($=6 \times 15$), we say it was under a pressure of six atmospheres.

119. **Different kinds of barometers.**—The instruments used for measuring the atmospheric pressure are called *barometers,* from two Greek words which signify *measure of weight* (air, of course, being understood). In ordinary barometers, the pressure is measured by the height of a column of mercury, as in Torricelli's experiment; the barometers which we are about to describe are of this kind. But there are barometers without *mercury,* one of which, the aneroid, is remarkable for its simplicity and portability.

120 **Cistern barometer.**—Ordinary barometers are classed as *syphon* and *cistern* barometers. Fig. 93 represents the usual form of the cistern barometer. It consists of a glass tube *ai*, closed at one end, about thirty-three inches long, and about half an inch in diameter.

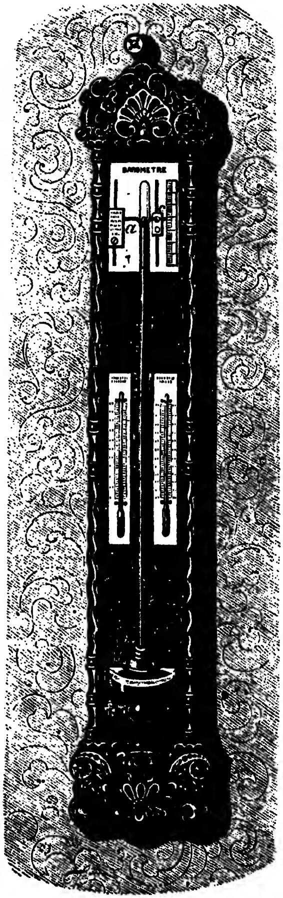

Fig. 93.

The tube is filled with mercury, and then its open end is inverted

in mercury contained in a glass vessel, A, of a peculiar shape; only the front half of this is visible, the other being fixed in a mahogany board which supports the whole barometer. The bottom of the cistern forms a spherical well, which is filled with mercury, and in which the tube *ai* is immersed. The tube is not fixed tightly in the neck, so that the atmospheric pressure can be freely transmitted to the mercury of the bath, and thus supports the column of mercury *ai*. If the pressure increases the mercury rises, if it decreases the mercury sinks.

At the top of the tube on the right is a scale divided in inches to measure the height of the mercury in the tube. The graduation starts from the zero which is level with the mercury in the bath. Hence, if the top of the mercury at *a* stands at thirty inches, for instance, this signifies that the height of the column of mercury is thirty inches. Only a portion of the scale is given, since, for ordinary purposes, the variations of the atmospheric pressure are within a few inches. Where greater variations occur, as in the use of the barometer for measuring heights, the graduated part must be larger.

It will be observed that the starting-point of the graduation, the zero, is at the level of the mercury in the cistern. But the zero of the scale does not always correspond to the level of the mercury in the cistern. For as the atmospheric pressure is not always the same, the height of the mercurial column varies: sometimes mercury is forced from the cistern into the tube, and sometimes from the tube into the cistern, so that, in the majority of cases, the graduation of the barometer does not indicate the true height. To diminish this source of error, the cistern has the form represented in fig. 93. Its upper part, that corresponding to the level of the mercury, is about four inches in diameter; so that, whether the mercury passes from the cistern into the tube, or from the tube into the cistern, as it is spread over a large surface the variations in the level are very small and may be neglected.

To complete this description it may be added, that on the scale is a small index, *c*, sliding along a vertical rod. When made level with the mercury this index points on the one side to the divisions on the graduated scale, and, on the other side, to certain inscriptions, the use of which will be afterwards stated (126). Lastly, in the middle of the tube are two thermometers, one with a Fahrenheit and the other with a Centigrade graduation.

121. **Fortin's barometer.**—*Fortin's barometer* (fig. 94) differs

from that just described, in the shape of the cistern. The base of the cistern is made of leather, and can be raised or lowered by means of a screw; this has the advantage, that a constant level can be obtained, and also that the instrument is made more portable. For, in travelling, it is only necessary to raise the leather until the mercury, which rises with it, quite fills the cistern; the barometer may then be inclined, and even inverted, without any fear that a bubble of air may enter, or that the shock of the mercury may crack the tube.

Fig. 94.

Fig. 95.

Fig. 95 shows the construction of the cistern. It consists of a glass cylinder, *b*, which allows the mercury to be seen; the bottom of the cylinder is cemented to a box-wood cylinder, *zz*, on which is firmly fixed at *ii* the chamois leather, *mn*, which is the base of the cistern. At the bottom of this leather is a small wooden button, *x*, against which the screw C works, by which it is raised or lowered. This screw works in the bottom of a brass cylinder, G, which is fastened on the glass cylinder. At the top of the cistern there is a small ivory pointer, *a*, the point of which exactly corresponds to the zero on the scale. The upper part of the cistern is closed by buckskin, *ce*, which is fastened to the barometer tube, E, and to a tubulure in the wooden disc, which covers the cistern. The barometer tube is drawn out at the open end, which is immersed in the mercury. The atmospheric pressure is transmitted through the pores of the leather. In using this barometer, the mercury is first made level with the point *a*, which is effected by turning the screw C either in one direction or the other. In this manner the distance of the top, B, of the column of mercury from the ivory point *a*, gives

exactly the height of the barometer. For the graduation is measured from the point *a*. Lastly, the lower part of the cistern is enclosed in a brass case, which is connected with the lid by three screws *k*, *k*, *k*. To the cistern is screwed a long brass case, which encloses the whole of the tube, as seen in figure. At the top of this case there are two longitudinal slits, on opposite sides, so that the level of the mercury, B, is seen. The scale on the case is graduated in millimeters or in inches. An index, A, moved by the hand, gives, by means of a vernier, the height of the mercury to $\frac{1}{10}$ of a millimeter. At the

Fig. 96.

Fig. 97.

Fig. 98.

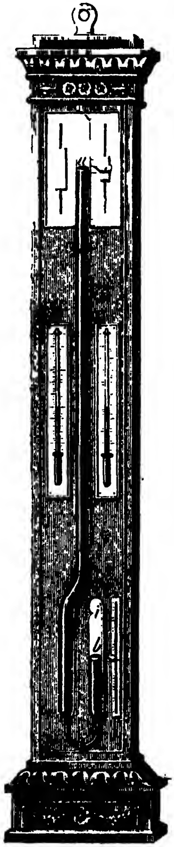

Fig. 99.

bottom of the case is affixed a thermometer to indicate the temperature.

122. **Gay-Lussac's syphon barometer.**—The syphon barometer has no cistern, but consists of a bent glass tube (fig. 96), one of the branches of which is much longer than the other. The longer branch, which is closed at the top, is filled with mercury as in the cistern barometer, while the shorter branch, which is open, serves as a cistern. The difference between the two levels is the height of the barometer.

Fig. 96 represents the syphon barometer as modified by Gay-Lussac. In order to render it more available for travelling, by preventing the entrance of air, he joined the two branches by a capillary tube: when the instrument is inverted (fig. 97), the tube always remains full in virtue of its capillarity, and air cannot penetrate into the longer branch, which, of course, is absolutely necessary. A sudden shock, however, might separate the mercury and admit some air. To avoid this M. Bunten has introduced an ingenious modification into the apparatus. The longer branch, A, is drawn out to a fine point, and is joined to a tube, B, of the form represented in fig. 98. By this arrangement, if air passes through the capillary tube, it cannot penetrate the drawn-out extremity of the longer branch, but lodges in the upper part of the enlargement B. In this position it does not affect the observations, since the vacuum is always at the upper part of the tube; it is, moreover, easily removed.

In Gay-Lussac's barometer the shorter branch is closed, but there is a lateral capillary aperture *i*, through which the atmospheric pressure is transmitted.

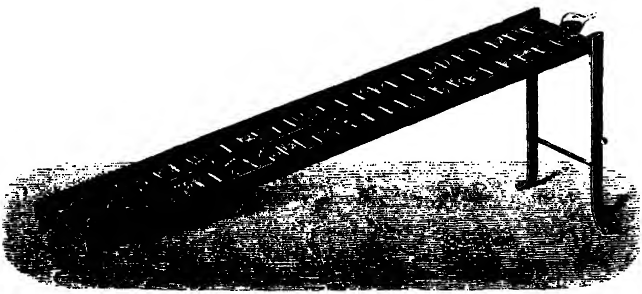

Fig. 100.

The barometric height is determined by means of two scales, which have a common zero at the middle of the longer branch, and

are graduated in contrary directions, the one from the middle to *a*, and the other from the middle to *b*, either on the tube itself, or on brass rules fixed parallel to the tube. Two sliding indexes are moved until they correspond to the level of the mercury in *a* and *b*. The total height of the barometer *ab* is the sum of the distances from the middle to *a* and *b* respectively.

123. **Precautions in reference to barometers.**—In constructing barometers, mercury is chosen in preference to any other liquid. For being the densest of all liquids it stands at the least height. When the mercurial barometer stands at thirty inches, the water barometer would stand at about thirty-four feet. It also deserves preference because it does not moisten the glass. It is necessary that the mercury be pure and free from oxide; otherwise it adheres to the glass and tarnishes it. Moreover, if it is impure its density is changed, and the height of the barometer is too great or too small. Mercury is purified, before being used for barometers, by treatment with dilute nitric acid, and by distillation.

The space at the top of the tube (figs. 96 and 99), which is called the *Torricellian vacuum*, must be quite free from air and from aqueous vapour, for otherwise either would depress the mercurial column. Now, glass tubes always condense aqueous vapour on their surface. Under the ordinary pressure of the atmosphere, this layer of moisture adhered to the glass; but in a vacuum where there is no pressure it escapes, and there is formed a mixture of air and aqueous vapour which tends to depress the mercurial column.

The air and moisture can only be got rid of by boiling the mercury in the tube. To obtain this result, a small quantity of pure mercury is placed in the tube and boiled for some time, fig. 100. It is then allowed to cool, and a further quantity, previously warmed, added, which is boiled, and so on, until the tube is quite full; in this manner the moisture and the air which adhere to the sides of the tube pass off with the mercurial vapour. The bulb at the end is placed there to collect the mercury which may distil over. It is afterwards removed.

A barometer is free from air and moisture if, when it is inclined, the mercury strikes with a sharp metallic sound against the top of the tube. If there is air or moisture in it, the sound is deadened.

X 124 **Variations in the height of the barometer.**—When the barometer is observed for several days, its height is found to vary

in the same place, not only from one day to another, but also during the same day.

The extent of these variations, that is, the difference between the greatest and the least height, is different in different places. It increases from the equator towards the poles. The greatest variations are observed in winter.

The *mean daily height* is the height obtained by dividing the sum of 24 successive hourly observations by 24. In our latitudes, the barometric height at noon corresponds to the mean daily height.

The *mean monthly height* is obtained by adding together the mean daily heights for a month, and dividing by 30.

The *mean yearly height* is similarly obtained.

Under the equator, the mean annual height at the level of the sea is $0^{m}\cdot758$, or 29·84 inches. It increases from the equator, and between the latitudes 30° and 40°, it attains a maximum of $0^{m}\cdot763$, or 30·04 inches. In lower latitudes it decreases, and in Paris it does not exceed $0^{m}\cdot7568$.

The general mean at the level of the sea is $0^{m}\cdot761$ or 29·96.

The mean monthly height is greater in winter than in summer, in consequence of the cooler atmosphere.

Two kinds of variations are observed in the barometer: 1st, the *accidental variations*, which present no regularity; they depend on the seasons, the direction of the winds, and the geographical position, and are common in our climates: 2nd, the *daily variations*, which are produced periodically at certain hours of the day.

At the equator, and between the tropics, no acccidental variations are observed; but the daily variations take place with such regularity that a barometer may serve to a certain extent as a clock. The barometer sinks from midday till towards four o'clock; it then rises, and reaches its maximum at about ten o'clock in the evening. It then again sinks, and reaches a second minimum towards four o'clock in the morning, and a second maximum at ten o'clock.

In the temperate zones there are also daily variations, but they are detected with difficulty, since they occur in conjunction with accidental variations.

The hours of the maxima and minima appear to be the same in all climates, whatever be the latitude; they merely vary a little with the seasons.

125. **Causes of barometric variations.**—It is observed that

the course of the barometer is generally in the opposite direction to that of the thermometer; that is, that when the temperature rises the barometer falls, and *vice versâ*; which indicates that the barometric variations at any given place are produced by the expansion or contraction of the air, and therefore by its change in density. If the temperature were the same throughout the whole extent of the atmosphere, no currents would be produced, and, at the same height, the atmospheric pressure would be everywhere the same. But when any portion of the atmosphere becomes warmer than the neighbouring parts, its specific gravity is diminished, and it rises and passes away through the upper regions of the atmosphere; whence it follows that the pressure is diminished, and the barometer falls. If any portion of the atmosphere retains its temperature, while the neighbouring parts become cooler, the same effect is produced; for in this case, too, the density of the first-mentioned portion is less than that of the others. Hence, also, it usually happens, that an extraordinary fall of the barometer at one place is counterbalanced by an extraordinary rise at another place. The daily variations appear to result from the expansions and contractions which are periodically produced in the atmosphere by the heat of the sun during the rotation of the earth.

X 126. **Relation of barometric variations to the state of the weather.**—It has been observed that, in our climate, the barometer in fine weather is generally above 30 inches, and is below this point when there is rain, snow, wind, or storm, and also, that for any given number of days at which the barometer stands 30 inches, there are as many fine as rainy days. From this coincidence between the height of the barometer and the state of the weather, the following indications have been marked on the barometer, counting by thirds of an inch above and below 30 inches:

Height	State of the weather
31 inches	Very dry.
$30\frac{2}{3}$ "	Settled weather.
$30\frac{1}{3}$ "	Fine weather.
30 "	Variable.
$29\frac{2}{3}$ "	Rain or wind.
$29\frac{1}{3}$ "	Much rain.
29 "	Tempest.

In using the barometer as an indicator of the state of the weather, we must not forget that it really only serves to measure the weight

of the atmosphere and that it only rises or falls as this weight increases or diminishes; and although a change of weather frequently coincides with a change in the pressure, they are not necessarily connected. This coincidence arises from meteorological conditions peculiar to our climate, and does not always occur. That a fall in the barometer usually precedes rain in our latitudes, is caused by the position of Europe. The south-west winds, which are hot, and consequently light, make the barometer sink; but at the same time as they become charged with aqueous vapour in crossing the ocean, they bring us rain. The winds of the north and north-east, on the contrary, being colder and denser, make the barometer rise; and, as they only reach us after having passed over vast continents, they are generally dry.

When the barometer rises or sinks slowly, that is, for two or three days, towards fine weather or towards rain, it has been found, from a great number of observations, that the indications are then extremely probable. Sudden variations in either direction indicate bad weather or wind.

127. **Wheel barometer.**—The *wheel barometer*, which was invented by Hooke, is a syphon barometer, and is especially intended to indicate good and bad weather (fig. 101). In the shorter leg of the syphon there is a float *a*, which rises and falls with the mercury (fig. 102). A string attached to this float passes round a pulley, and at the other end there is another and somewhat lighter float. A needle fixed to the pulley moves round a graduated circle, on which is marked *variable*, *rain*, *fine weather*, etc. When the pressure varies the float sinks or rises, and moves the needle round to the corresponding points on the scale.

The barometers ordinarily met with in houses, and which are called *weather glasses*, are of this kind. They are, however, of little use, for two reasons. The first is, that they are neither very delicate nor precise in their indications. The second, which applies equally to all barometers, is, that those commonly in use in this country are made in London, and the indications, if they are of any value, are only so for a place of the same level and of the same climatic conditions as London. Thus a barometer standing at a certain height in London would indicate a certain state of weather, but if removed to Shooter's Hill it would stand half an inch lower, and would indicate a different state of weather. As the pressure differs with the level and with geographical conditions, it is necessary to take these into account if exact data are wanted.

128. **Determination of the heights of places by the barometer.**—One of the most important of the uses of the barometer has been its application to the measurement of the heights of places above the sea level. For, if we suppose the atmosphere

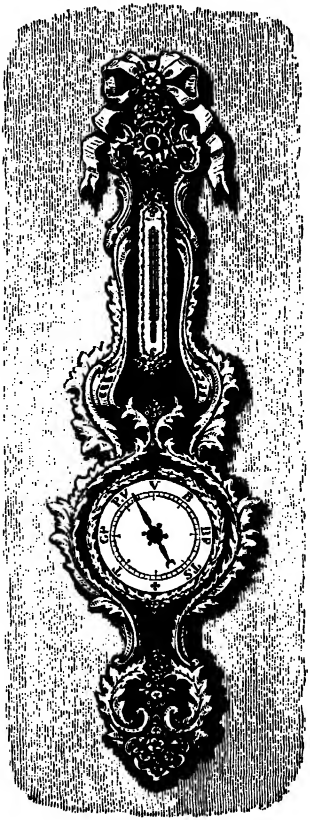

Fig. 101.

Fig. 102.

divided into horizontal layers of equal thickness, a hundred, for instance, a barometer at the sea level would support the weight of a hundred of these layers; and, as we have seen (116), would be at rest when its height was thirty inches. If it were raised in the atmo-

sphere to the height of ten such layers, it would now only support the weight of ninety such layers, and the mercury would therefore necessarily sink. It would sink still further if it were raised to the twentieth layer, and so on to the limit of the atmosphere if that were possible. There it would be under no pressure, and the level of the mercury in the tube and in the cistern would be the same.

As the mercury sinks in proportion as we rise in the atmosphere, we might, from the amount by which it is lower, deduce the height above the sea level. If air had everywhere the same density up to the extreme limit of the atmosphere, the calculation would be very simple; for as mercury is about 10,500 times as heavy as air, an inch of the barometer would correspond to a column of air about 875 feet; hence, in ascending a mountain, a diminution of an inch in the height of the barometer would correspond to an ascent of about 875 feet. But the density of the air decreases as we ascend, for the layers of air necessarily support a less weight; hence, the measurement of the heights by the barometer is not so simple as we have supposed. Very complete tables have, however, been constructed, by which the difference in height between any two places may be readily ascertained, if we know the corresponding height of the barometer. For small elevations we may assume that an ascent of 900 feet produces a depression of an inch in the height of the barometer.

129. **Height of the atmosphere.**—In virtue of the expansive force of the air, it might be supposed that the molecules would expand indefinitely into the planetary spaces. But, in proportion as the air expands, its expansive force decreases, and is further weakened by the low temperature of the upper regions of the atmosphere, so that, at a certain height, an equilibrium is established between the expansive force which separates the molecules, and the action of gravity which draws them towards the centre of the earth. It is therefore concluded that the atmosphere is limited.

From the weight of the atmosphere, and its decrease in density, and from the observation of certain phenomena of twilight, its height has been estimated at from 30 to 40 miles. Above that height the air is extremely rarefied, and at a height of 60 miles it is assumed that there is a perfect vacuum. From certain observations recently made in the tropical zone, and particularly at Rio Janeiro, on the twilight arc, M. Liais estimates the height of the atmosphere at between 198 and 212 miles, considerably higher, therefore, than what has hitherto been believed.

ILLUSTRATIONS OF ATMOSPHERIC PRESSURE.

130. **The pressure of the atmosphere is transmitted in all directions.**—The atmosphere, like any other mass of fluid (75) must necessarily transmit its pressure in all directions, upwards and laterally as well as downwards. We have already seen a striking instance of this in the Magdeburg hemispheres, (115) and the following experiment furnishes another illustration of this point.

A tumbler full of water is carefully covered with a sheet of paper, which is kept in position by one hand, while with the other the tumbler is inverted. Removing then the hand which held the paper, the water does not fall out, both water and paper being kept in position by the upward pressure (fig. 103). The object of the paper is to present a flat surface of water, for otherwise the water would divide and would allow air to enter, and then the experiment would fail.

The use of the *wine-tester* also depends on the pressure of the

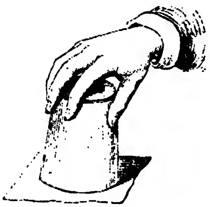

Fig. 103.

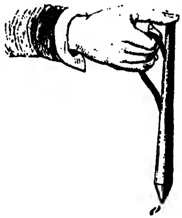

Fig. 104.

atmosphere. It consists of a tin tube (fig. 104), terminating at the bottom in a small cone, the end of which, *o*, is open; at the top there is a small aperture, which is closed by the thumb. The two ends being open, the tube is immersed in the liquid to be tested; closing then the upper end by the thumb, as shown in the figure, the tube is withdrawn, and remains filled in consequence of the pressure at *o*. But if the thumb be withdrawn the pressure is transmitted both upwards and downwards, and the liquid flows out in obedience to the action of gravity.

131. **Pressure supported by the human body.**—The surface of the body of a man of middle size is about 16 square feet; the pressure, therefore, which a man supports on the surface of his

body is 37,560 pounds, or upwards of 16 tons. Such an enormous pressure might seem impossible to be borne; but it must be remembered that in all directions there are equal and contrary pressures which counterbalance one another. It might also be supposed that the effect of this force, acting in all directions, would be to press the body together and crush it. But the solid parts of the skeleton could resist a far greater pressure; and as to the liquids contained in the organs and vessels, from what has been said about liquids, (74) it is clear that they are virtually incompressible.

The gases, too, are compressed by the weight of the atmosphere; but they resist it in virtue of their elasticity. They are, in short, like a bottle full of air. The sides of the latter are pressed in by the weight of the atmosphere; but they can stand this, however thin their walls, for the pressure of the gas from within quite counterbalances that which presses externally.

Fig. 105.

The following experiment (fig. 105) illustrates the effect of atmospheric pressure on the human body. A glass vessel, open at both ends, being placed on the plate of the machine, the upper end of the cylinder is closed by the hand, and a vacuum is made. The hand then becomes pressed by the weight of the atmosphere, and can only be taken away by a great effort. And as the elasticity of the gas contained in the organs is not counterbalanced by the weight of the atmosphere, the palm of the hand swells, and blood tends to escape from the pores.

The operation of cupping in medicine is an application of the effect of removing the atmospheric pressure from the human body.

CHAPTER II.

MEASUREMENT OF THE ELASTIC FORCE OF GASES.

132. **Boyle's law.**—The law of the compressibility of gases was discovered by Boyle, and subsequently, though independently, by Mariotte. In consequence it is in England commonly called

Boyle's law, and, on the Continent, Mariotte's law. It is as follows: '*The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure which it bears.*'

This law is verified by means of an apparatus called *Mariotte's tube* (fig. 106). It consists of a long glass tube fixed to a vertical

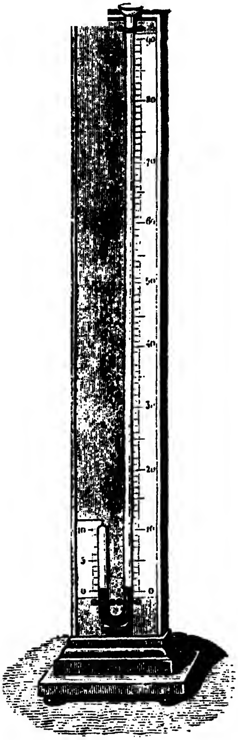

Fig. 106.

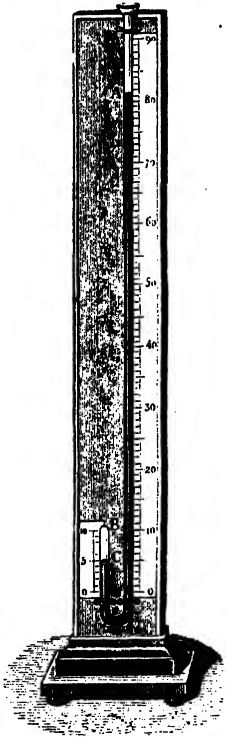

Fig. 107.

support: it is open at the upper part; and the other end, which is bent into a short vertical leg, is closed. On the shorter leg there is a scale, which indicates equal capacities; the scale against the long leg gives the heights. The zero in both scales is in the same horizontal line.

A small quantity of mercury is poured into the tube, so that its level

in both branches is at zero, which is effected without much difficulty. The air in the short leg is thus under the ordinary atmospheric pressure. If mercury is then poured into the longer tube the volume of the air in the smaller tube is gradually reduced. If this be continued until it is only one-half, that is, until it is reduced from 10 to 5, as shown in figure 107, and if the height of the mercurial column, CA, be now measured, it will be found exactly equal to the height of the barometer at the time of the experiment. The pressure of the column CA is therefore equal to an atmosphere, which, with the atmospheric pressure acting on the surface of the column at C, makes two atmospheres. Accordingly, by doubling the pressure, the volume of the gas has been diminished to one-half.

If mercury be poured into the longer branch until the volume of the air is reduced to one-third its original volume, it will be found that the distance between the level of the two tubes is equal to two barometric columns. The pressure is now three atmospheres, while the volume is reduced to one-third. Dulong and Petit have verified the law for air up to 27 atmospheres, by means of an apparatus analogous to that which has been described.

The law also holds good in the case of pressures of less than one atmosphere. To establish this, mercury is poured into a graduated tube, until it is about two-thirds full, the rest being air. It is then inverted in a deep trough containing mercury (fig. 108), and lowered until the levels of the mercury inside and outside the tube are the same, and the volume AB, which is then under a pressure of one atmosphere, is noted. The tube is then raised, as represented in fig. 109, until the volume of the air, AC, is doubled. The height of the

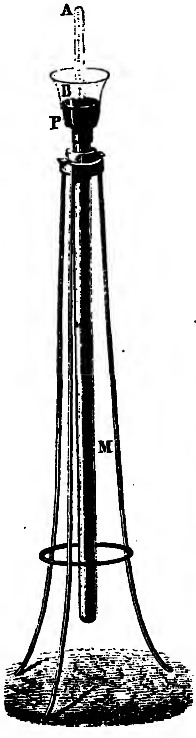

Fig. 108.

Fig. 109.

mercury in the tube, above the mercury in the trough, is then found to be exactly half the height of the barometric column. Accordingly, for half the pressure the volume has been doubled.

In the experiment with Mariotte's tube, as the quantity of air remains the same, its density must obviously increase as its volume diminishes, and *vice versâ*. The law may thus be enunciated: '*For the same temperature the density of a gas is proportional to its pressure.*' Hence, as water is 770 times as heavy as air, under a pressure of 770 atmospheres, air would be as dense as water.

Until within the last few years Boyle's law was supposed to be absolutely true for all gases at all pressures; but several physicists have since observed that the gas is not rigorously exact, especially in the case of those gases which can be liquefied. They are more compressed than is required by the law. For air, Dulong and Arago investigated the pressure up to 27 atmospheres, and observed that the volume of air always diminished a little more than is required by Boyle and Mariotte's law. But, as these differences were very small, they attributed them to errors of observation, and concluded that the law was perfectly exact, at any rate up to 27 atmospheres.

For ordinary pressures Boyle's law may be assumed to be sufficiently near for all gases.

133. **Manometers.**—*Manometers* are instruments for measuring the elastic force of gases or vapours. In all manometers the unit chosen is the pressure of one atmosphere, or 30 inches of mercury at the standard temperature, which, as we have seen, is nearly 15lbs. to the square inch. The open air *manometer* is represented in fig. 110 fixed against a board fastened to a wall, and connected with a steam boiler. It consists of a glass tube about 20 feet in height, open at the top, and fixed at the other end to a glass bath C, containing mercury. A long tube connects this with the boiler.

When the elastic force of the vapour in the boiler is equal to the pressure of the atmosphere, it will counterpoise the weight of the atmosphere which is transmitted through the tube, and the level of the mercury is then the same in the tube and in the bath. At this level the number 1 is marked on the board. Then since a column of mercury 30 inches in height represents a pressure of an atmosphere, the number 2 is marked at this height above 1; at a height of 30 inches above this the number 3 is marked, and so on, each interval of 30 inches representing an atmosphere. Thus, for instance, if the mercury had been forced up to 3½, as represented in

the drawing, that would indicate that the tension of the vapour in the boiler is 3½ atmospheres; so that, on each square inch of the internal surface of the boiler, there is a pressure of 3½ × 15 pounds, or 52½ pounds.

The manometer with *compressed air* is founded on Mariotte's law;

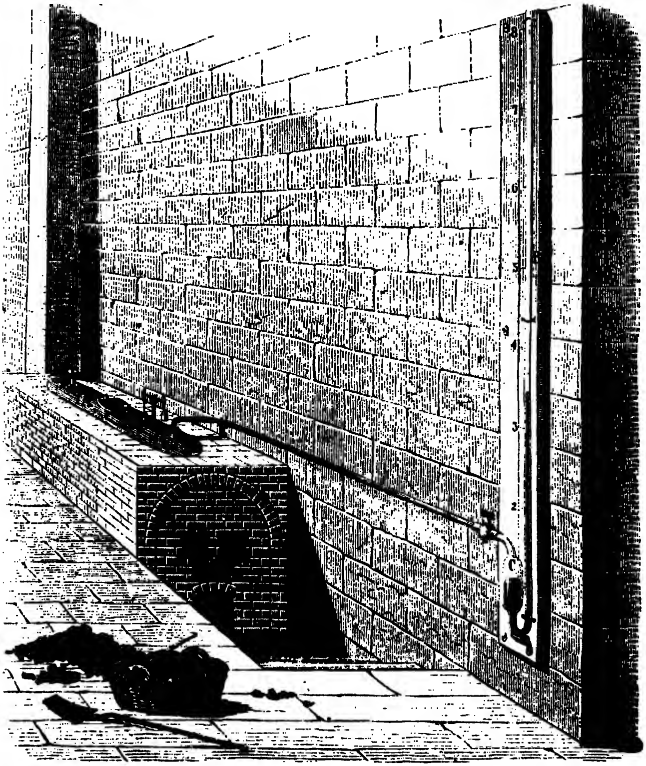

Fig. 110.

it consists of a glass tube closed at the top (fig. 111), and filled with dry air. It is firmly cemented in a small bath containing mercury. By a tubulure, this bath is connected with the closed

vessel containing all the gas or vapour whose tension is to be measured.

In the graduation of this manometer, the quantity of air contained in the tube is such, that when the aperture communicates freely with the atmosphere, the level of the mercury is the same in the tube and in the bath. Consequently, at this level, the number 1 is marked on the scale to which the tube is affixed. As the pressure acting through the tubulure A increases, the mercury rises in the tube, until its weight added to the tension of the compressed

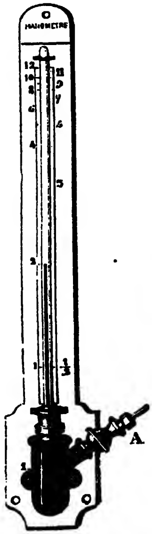

Fig. 111.

Fig. 112.

air, is equal to the external pressure. It would consequently be incorrect to mark two atmospheres in the middle of the tube; for since the volume of the air is reduced to one-half, its tension is equal to two atmospheres, and, together with the weight of the mercury raised in the tube, is therefore more than two atmospheres. The position of the number is a little below the middle, at such a height that the elastic force of the compressed air, together with the weight of the mercury in the tube, is equal to two atmospheres. The exact position of the numbers 2, 3, 4, etc., on the manometer scale can only be determined by calculation.

134. **Aneroid barometer.**—This instrument derives its name from the circumstance that no liquid is used in its construction (ἀ, without, νηρὸς, moist). Fig. 112 represents one of the forms of these instruments, constructed by Mr. Casella; it consists of a cylindrical metal box, exhausted of air, the top of which is made of thin corrugated metal, so elastic that it readily yields to alterations in the pressure of the atmosphere.

When the pressure increases, the top is pressed inwards; when on the contrary it decreases, the elasticity of the lid, aided by a spring, tends to move it in the opposite direction. These motions are transmitted by delicate multiplying levers to an index which moves on a scale. The instrument is graduated empirically by comparing its indications under different pressures with those of an ordinary mercurial barometer.

The aneroid has the advantage of being portable, and can be constructed of such delicacy as to indicate the difference in pressure between the height of an ordinary table and the ground. It is hence much used in determining heights in mountain ascents. But it is liable to get out of repair, especially when it has been subjected to great variations of pressure; and its indications must from time to time be compared by means of a standard barometer.

MIXTURE AND SOLUTION OF GASES.

135. **Laws of the mixture of gases.**—We have seen that liquids, when they do not act chemically, tend continually to separate, and to become superposed in the order of their densities. This is not the case with gases; being under a continual tendency to expand, when they mix, their mixture is found to be subject to the following laws:

I. *Whatever their densities, gases mix in equal proportions in all parts of the vessel in which they are contained.*

II. *The elastic force of the mixture is equal to the sum of the elastic forces of the constituents.*

The first law was shown experimentally by Berthollet, by means of an apparatus represented in fig. 113. It consisted of two glass globes provided with stopcocks, which could be screwed one on the other. The upper globe was filled with hydrogen, and the lower one with carbonic acid, which has 22 times the density of hydrogen. The globes having been fixed together were placed in the cellars of the Paris Observatory, and the stopcocks then

opened, the globe containing hydrogen being uppermost. Berthollet found, after some time, that the pressure had not changed, and that, in spite of the difference in density, the two gases had become uniformly mixed in the two globes. Experiments made in the same manner with other gases gave the same results, and it was found that the diffusion was more rapid in proportion as the difference between the densities was greater.

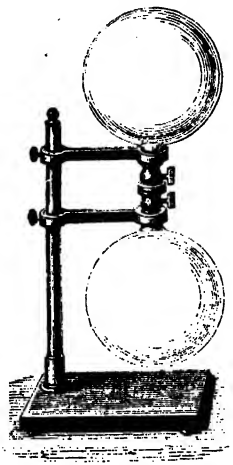

Fig. 113.

In accordance with this law, air being a mixture of nitrogen and oxygen, which are different in density, its composition should be the same in all parts of the atmosphere, which in fact is what has been observed.

Gaseous mixtures follow Boyle and Mariotte's law, like simple gases, as has been proved for air (132), which is a mixture of nitrogen and oxygen.

136. **Mixture of gases and liquids. Absorption.**—Water and many liquids possess the property of absorbing gases. Under the same conditions of pressure and temperature a liquid does not absorb equal quantities of different gases. At the ordinary temperature and pressure water dissolves $\frac{25}{1000}$ its volume of nitrogen, $\frac{46}{1000}$ its volume of oxygen, its own volume of carbonic acid, and 430 times its volume of ammoniacal gas.

The general laws of gas-absorption are the following :

I. *For the same gas, the same liquid, and the same temperature, the weight of gas absorbed is proportional to the pressure.* This may also be expressed by saying that at all pressures the volume dissolved is the same ; or that the density of the gas absorbed is in a constant relation with that of the external gas which is not absorbed.

Accordingly, when the pressure diminishes, the quantity of dissolved gas decreases. If a solution of a gas be placed under the air-pump and a vacuum created, the gas obeys its expansive force and escapes with effervescence.

The manufacture of aerated water is a practical application of this law. By means of force-pumps an excess of carbonic acid is

dissolved in the water, and the solution is then preserved in carefully closed vessels.

It is the carbonic acid dissolved in beer, in champagne, and in all effervescing liquids, which, rapidly escaping when the bottles are uncorked, produces the well-known report, and carries with it a greater or less quantity of the liquid.

II. *The quantity of gas absorbed is greater when the temperature is lower*; that is to say, when the elastic force of the gas is less.

III. *The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of other gases which it may already hold in solution.*

CHAPTER III.

APPARATUS FOUNDED ON THE PROPERTIES OF AIR.

137. **Air-pump.**—The air-pump is an instrument by which a vacuum can be produced in a given space, or rather by which air can be greatly rarefied, for an absolute vacuum cannot be produced by its means. It was invented by Otto von Guericke in 1650, a few years after the invention of the barometer.

Fig. 114 gives a perspective view of the pump, fig. 115 gives a detailed longitudinal section, and fig. 116 gives a cross section.

The pump consists of two stout glass barrels in which two pistons, P and Q, made of leather well soaked with oil, move up and down, and close the barrels air-tight. The pistons are fixed to two racks, A and B, working with a pinion (K, fig. 116), which is moved by a handle MN, so that, when one piston rises, the other descends.

The two barrels are firmly cemented on the base, H, which is of brass ; on this plate is a column, I, terminated by a plate, G. On this plate is a glass bell jar which is called the *receiver.* In the interior of the column is a conduit, which is prolonged below the base to between the two barrels. It there branches in the shape of a T, terminating in two apertures, *a* and *b*, in the bottom of the cylinders. These apertures are conical, and are closed by two small conical valves ; these latter are fixed to metal rods which work air-tight, but with gentle friction in the pistons. In the pistons is a cylindrical cavity communicating with the lower part of the pump by two apertures, *s* and *t* (fig. 116). These apertures are closed by small clack

valves, kept in position by springs which surround the rods themselves. The four valves, *a*, *b*, *s*, *t*, it may be remarked, open upwards.

These details being known, the working of the machine is readily understood. It is sufficient to consider what takes place in a single

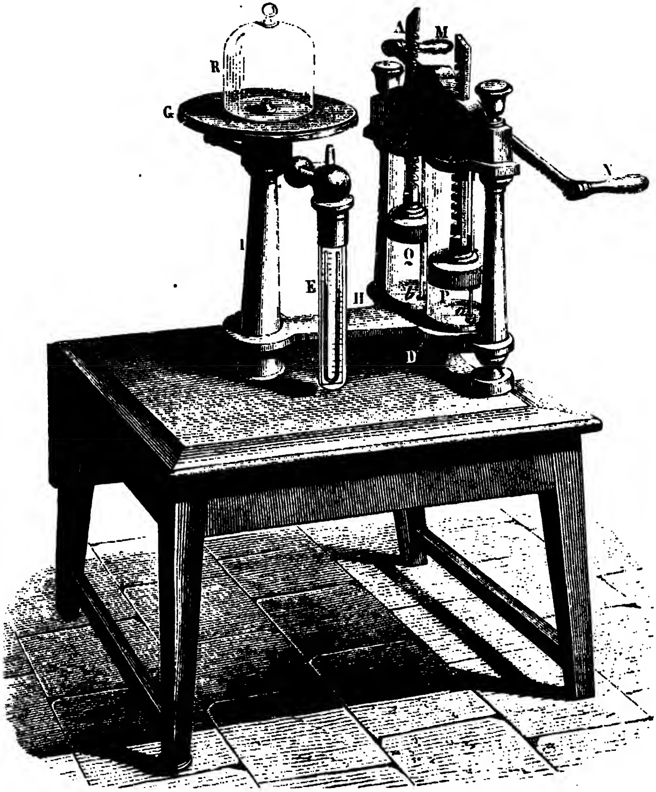

Fig. 114.

piston (fig. 114). The piston P being first at the bottom of its stroke, on rising it raises the rod which traverses it, and therewith the valve *a*, which remains open during the ascent. The valve, *t*, which is in the piston, remains closed by the action of the spring and the pressure of the atmosphere, which acts in the barrel

through an aperture, *r*, in the cover. From this position of the two valves, it will be seen that, as the piston rises, the external pressure of the atmosphere cannot act in the bottom of the barrel, but the air of the receiver, in virtue of its elasticity, expands and passes by the conduit, I and A, into the barrel. The receiver is still full of air, but it is more rarefied; it is less dense.

When the piston descends, the rod which bears the valve, *a*, descending with it, communication between the receiver and the

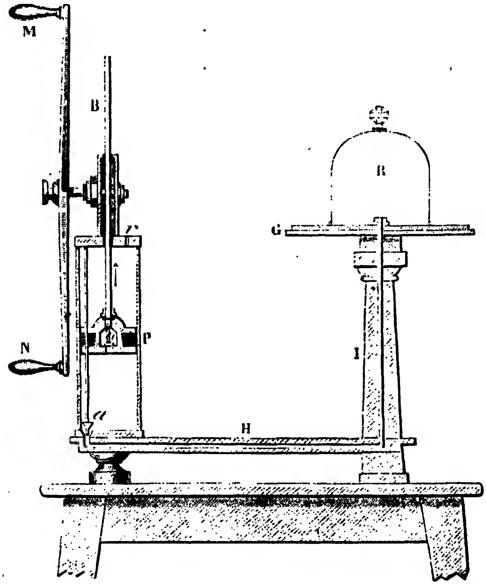

Fig. 115.

barrel is cut off. The air in the barrel becomes more and more compressed, its elastic force increases, and finally overcomes the atmospheric pressure; so that the valve *t*, being pressed upwards by the elastic force of the air in the interior more strongly than it is pressed downwards by the atmosphere, is raised, and allows the air of the barrel to escape into the upper part of the barrel, and thence into the atmosphere. Thus a certain quantity of air has been removed. A fresh quantity is removed at a second stroke of

the piston, another at the third, and so on. The air in the receiver is thus gradually more and more rarefied; yet all the air cannot be entirely extracted, for it ultimately becomes so rarefied both in the receiver and in the barrel, that when the piston P is at

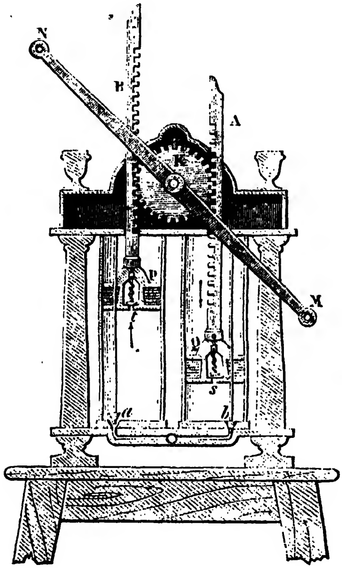

Fig. 116.

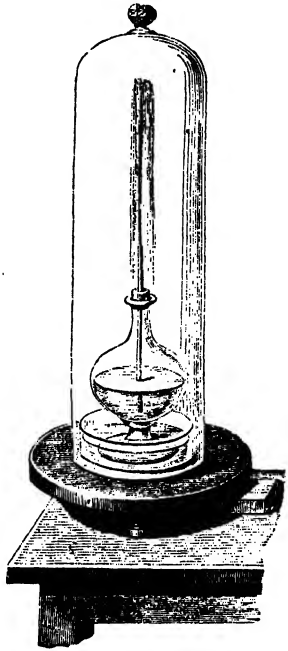

Fig. 117.

the bottom of its stroke, the compressed gas below the piston has no longer sufficient force to overcome the resistance of the atmosphere and force open the valve *t*. The limit of rarefaction has then been attained, and it is useless to work the pump any longer.

What has been said in reference to one barrel applies also to the other. The machine works with one; and the first air-pumps had but one. The advantage of having two is that the vacuum is more rapidly produced. The use of double-action air-pumps was first introduced by Hawksbee.

138. **Measurement of the degree of rarefaction in the receiver.**—Since a perfect vacuum cannot be obtained in the receiver, it is useful to have a mean sof ascertaining the degree of rarefac-

tion at any particular time. This is effected by means of a glass cylinder, E, connected by a brass cap with the conduit in the column I (fig. 114). In this cylinder is placed a bent glass tube, closed at one end and open at the other. This is called the *air-pump gauge.* It is fixed against a plate, on which is a graduated scale. The closed branch being at first full of mercury, so long as the air in the receiver P and in the cylinder E has sufficient tension, it sustains the mercury in the tube; the height of which is from six to eight inches. But as the machine is worked the air becomes more and more rarefied, and has no longer the elastic force sufficient for retaining the column of mercury in the closed limb. It accordingly sinks in this limb and rises in the other. The greater the rarefaction, the smaller the difference of the level in the two limbs. They are, however, never exactly equal; which would correspond to a perfect vacuum. The mercury is always at least the $\frac{1}{20}$th of an inch higher in the closed branch. This is expressed by saying that a vacuum has been created within $\frac{1}{20}$th of an inch.

139. **Uses of the air-pump.**—A great many experiments with the air-pump have been already described. Such are the mercurial rain (fig. 14), the fall of bodies in vacuo (fig. 37), the bladder (fig. 87), the bursting of a bladder (fig. 89), the Magdeburg hemispheres (fig. 90), and the baroscope (fig. 132).

The *fountain in vacuo* (fig. 117) is an experiment made with the air-pump, and shows the elastic force of the air. It is a flask containing water and air; the neck is closed by a cork, through which passes a tube dipping in the liquid. The flask being placed under the receiver, a jet of water issues from the top of the tube as soon as the air is sufficiently rarefied. This is due to the elastic force of the air enclosed in the flask.

By means of the air-pump it may be shown that air, by reason of the oxygen it contains, is necessary for the support of combustion and of life. For if we place a lighted taper under the receiver and begin to exhaust the air, the flame becomes weaker as rarefaction proceeds, and is finally extinguished. Similarly an animal faints and dies, if a vacuum s formed in a receiver under which it is placed. Mammalia and birds soon die in vacuo. Fishes and reptiles support the loss of air for a much longer time. Insects can live several days in vacuo.

140. **Application of the vacuum to the preservation of food.**—An important application has been made of the vacuum in preserving food. In air, under the influence of heat, moisture, and

oxygen, animal and vegetable matters rapidly ferment and putrefy; but if the oxygen be removed, either by exhausting or by other means, they may be kept fresh for many years.

Appert of Paris was the first in 1809 to devise a means of preserving food in vacuo, or rather in a space deprived of oxygen, which practically amounts to the same. This method consists in placing the substances to be preserved in tin vessels, which are closed hermetically, and then heating in boiling water for some time, under the influence of heat the small quantity of oxygen left in the vessel is absorbed by the substance placed there, so that only nitrogen is present in the free state, a gas which cannot induce fermentation. Substances properly prepared in this manner may be kept for years without alteration.

Appert's method is modified in England in the following manner. Instead of boiling the food while contained in the closed vessel, a small hole is left in the lid, through which escape the air and vapours produced during ebullition. When it is supposed that all the air has been expelled, a drop of melted lead is allowed to fall on the small hole in the cover which completely closes it. This method is practised on the large scale in preserving food and vegetables for the use of sailors, and also in preserving Australian meat, which is now consumed in large quantities.

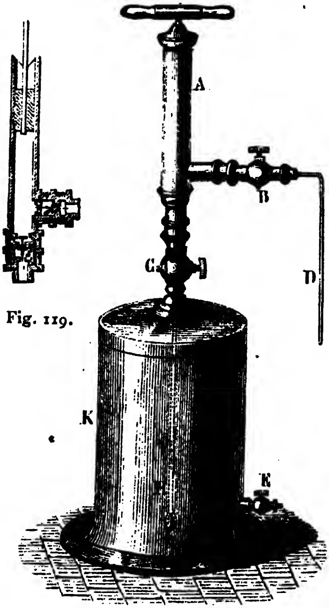

Fig. 119.

Fig. 118.

141. **Condensing pump.** — The condensing pump is an apparatus for compressing air or any other gas. The form usually adopted is the following: In a cylinder, A, of small diameter (fig. 118), there is a solid piston, the rod of which is moved by the hand. The cylinder is provided with a screw which fits into the receiver, K. Fig. 119 shows the arrangement of the valves, which are so constructed

that the lateral valve, *o*, opens from the outside, and the lower valve, *s*, from the inside.

When the piston descends, the valve *o* closes, and the elastic force of the compressed air opens the valve *s*, which thus allows the compressed air to pass into the receiver. When the piston ascends, *s* closes and *o* opens, and permits the entrance of fresh air, which in turn becomes compressed by the descent of the piston, and so on.

This apparatus is chiefly used for charging liquids with gases. For this purpose the stopcock B is connected with a reservoir of the gas, by means of the tube D. The pump exhausts this gas, and forces it into the vessel K, in which the liquid is contained. The artificial gaseous waters are made by means of analogous apparatus.

142. **Hero's fountain.**—Hero's fountain is an arrangement by which a jet may be obtained, which lasts for some time. It derives its name from its inventor, Hero, who lived at Alexandria, 120 B.C., and depends on the elasticity of the air. It consists of a brass dish (fig. 120), and of two glass globes. The dish communicates with the lower part of the globe by a long tube; and another tube connects the two globes. A third tube passes through the dish to the lower part of the upper globe. This tube having been taken out, the upper globe is partially filled with water, the tube is then replaced, and water is poured into the dish. The water flows through the long tube into the lower globe, and expels the air, which is forced into the upper globe; the air thus compressed, acts upon the water, and makes it jet out as represented in the figure. If it were not for the resistance of the atmosphere, and friction, the liquid would rise to a height above the water in the dish equal to the difference of the level in the two globes.

143. **Intermittent fountain.**—The *intermittent fountain* depends partly on the elastic force of the air and partly on the atmospheric pressure. It consists of a stoppered glass globe *a*, (fig. 121), provided with two or three capillary tubulures. A glass tube, *d*, open at both ends, reaches at one end to the upper part of the globe, *a*; the other end is fitted in a support, *c*, placed in the middle of the dish, *m*, which supports the whole apparatus. The support, *c*, is perforated with small holes, which allow air to pass into the tube just above a little aperture in the dish, *m*.

The water, with which the globe, *a*, is nearly two-thirds filled,

runs out by the tubes, as shown in the figure; the internal pressure being equal to the atmospheric pressure, together with the weight of the column of water, while the external pressure at that point is only that of the atmosphere. These conditions prevail so long as the lower end of the glass tube is open, that is, so long as

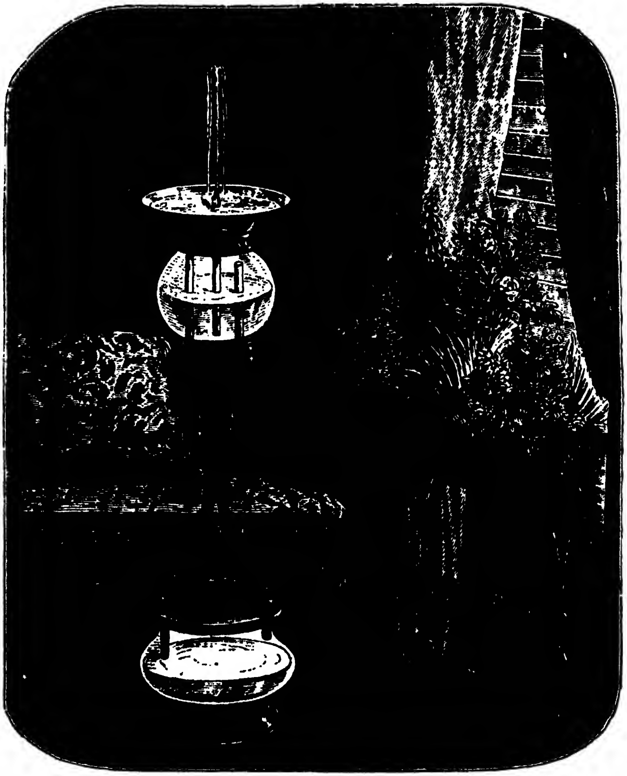

Fig. 120.

air can enter and keep the air in *a* at the same density as the external air; but the apparatus is arranged so that the orifice in the dish does not allow so much water to flow out as it receives from the upper tubes, in consequence of which the level gradually rises in the dish, and closes the lower end of the glass tube. As the ex-

ternal air cannot now enter the globe, *a*, the air becomes rarefied in proportion as the flow continues, until the pressure of the column of water, together with the tension of the air contained in the globe, is equal to this external pressure; the flow consequently stops. But as water continues to flow out of the dish at *m*, the

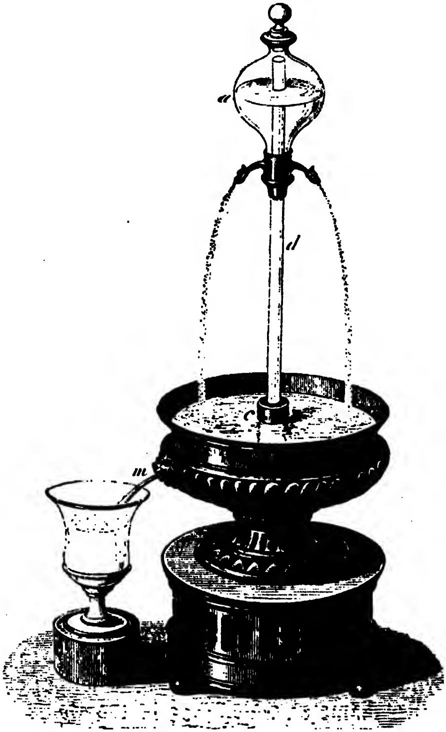

Fig. 121.

tube opens again, air enters, and the flow recommences, and so on, as long as there is water in the globe *a*.

144. **Syphon inkstand.**—This instrument, the object of which is to protect ink from too rapid evaporation by keeping it from contact with air, is an ingenious application of the pressure of the atmosphere, and of the elasticity of air. It consists of a glass vessel

of the shape of a truncated pyramid (fig. 122), closed everywhere except at the bottom, where there is a tubulure, which is always open.

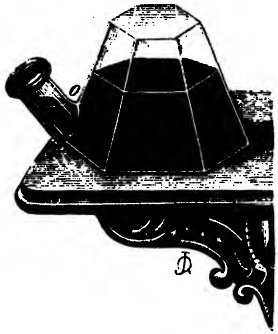

Fig. 122.

The inkstand is partially full of ink, while there is air at the top. The level of the ink inside being higher than in the tubulure, the elastic force of the air inside is a little less than the pressure of the atmosphere on the ink in the tubulure. As the ink there is used, its level sinks, and is finally lower than the point *o*. At this moment a bubble of air passes into the interior, and the elastic force being thereby increased, the level of the ink descends in the inside and rises in the tubulure. This goes on until the internal level is at the point *o*. More ink must then be added, which is effected by pouring it into the tubulure, care being taken to incline the inkstand in the opposite direction. The fountains in birdcages are on a similar principle.

DIFFERENT KINDS OF PUMPS.

145. **Suction-pump.**—Pumps are machines for raising liquids. Their invention, which is of great antiquity, is attributed to Ctesibius, a celebrated mechanician, who flourished at Alexandria, 130 B.C. There are many modifications of pumps, but they may all be referred to three types, *the suction or lift-pumps, the forcing pump, and the suction and forcing pump.*

The suction or lifting pump, represented in fig. 123, consists of a cast-iron cylinder called the *barrel*, at the bottom of which is a pipe of a smaller diameter, which dips in the well. At the top of this pipe is a clack valve, which is represented in the drawing as being open. As it can be raised and lowered without an effort, it establishes a communication between the cylinder and the body of the pump when it is open, and breaks it when closed. The piston in the barrel consists of a thick disc of metal, or of leather coated with tow or with leather. The piston is perforated by a small hole, which is closed by a valve; the valve is like that in the barrel, and, like it, opens upwards. The piston is worked by

means of a long lever, which is the *handle*. This is joined at one end to a forked rod, *a*, which is connected with the piston rod, *b*. As it is important that the piston move in a straight line, it is guided by passing through a hole in a fixed piece, *o*.

Fig. 123.

The manner in which the water is raised will be understood from an inspection of figs. 124, 125, and 126, which represent the piston and the valves in three different positions. When the pump has not been worked, the barrel and the pipe are full of air under the ordinary atmospheric pressure, which counterbalances the external atmospheric pressure on the well. Hence it follows

that the level of the water inside and outside is the same. When the piston rises (fig. 124), as it is pressed down by its own weight

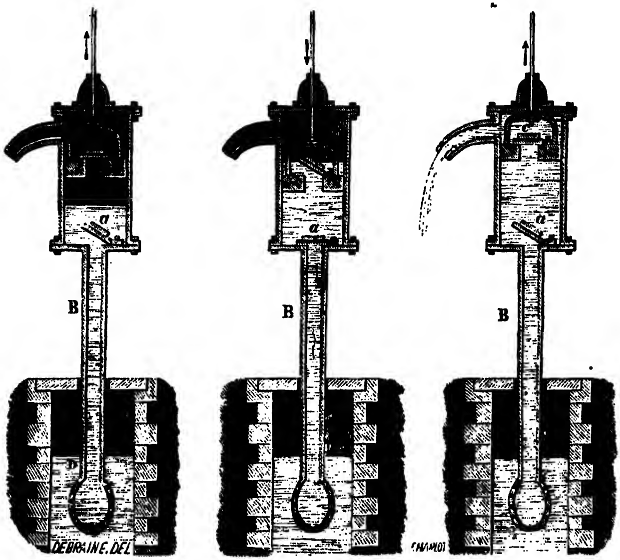

Fig. 124. Fig. 125. Fig. 126.

and that of the atmosphere, a vacuum is created below the piston; but, in virtue of its elastic force, the air which fills the pipe B quickly opens the valve, *a*, and passes into the barrel. The air in the pipe B losing then in elastic force what it gains in volume (132), its tension is no longer equal to the external pressure on the water in the well. Hence water rises in the pipe, as represented in the diagram. If now the piston sinks, the valve *a* closes; and as the air thus enclosed in the barrel becomes more and more compressed, a moment arrives when its elastic force exceeding the pressure of the atmosphere, the valve *c* is raised, and air escapes into the top of the barrel, and thence into the atmosphere. With a second ascending stroke of the piston, the same phenomena are reproduced; that is, *c* falls and the valve *a* opens, the water being thus raised in the pipe, ultimately passes beyond the valve *a*, and completely fills the barrel. From this time, when the piston re-descends, and the valve *a* closes, water

being compressed, raises the valve *c*, and passes above the piston (fig. 125). Once this effect is produced, when the piston ascends, the valve *c* closes, and the water which has passed above the piston being raised with it, ultimately flows out by a lateral tubulure in the barrel (fig. 126).

Since it is the atmospheric pressure which raises the water in the pipe, the height of the valve *a*, above the level in the vessel, cannot exceed a certain limit. A column of water, 34 feet in height, balances, as we have seen, the pressure of the atmosphere (117). Hence if the pipe had a greater length than this, when once water had reached this height, the column of water in the pipe would balance the pressure of the atmosphere on the water of the well, and it could not be raised any higher. Hence this would be the extreme theoretical limit which the pipe could have; but in practice the height of the tube A does not often exceed 26 to 28 feet; for, although the atmospheric pressure can support a higher column, the vacuum produced in the barrel is not perfect, owing to the fact that the piston does not fit exactly on the bottom

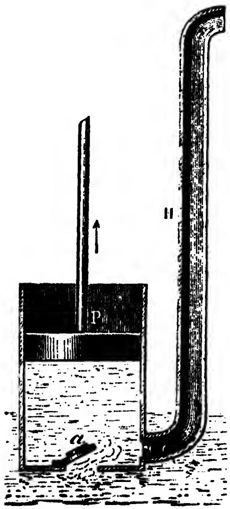

Fig. 127.

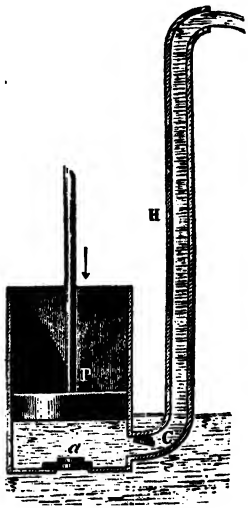

Fig. 128.

of the barrel. But when the water has passed the piston, it is the lifting force of the latter which raises it, and the height to

which it can be brought depends on the force which moves the piston.

146. **Force-pump.**—In these water is not raised by the pressure of the atmosphere, but by the pressure of the piston on the water during its descent. For this purpose the piston is solid, that is, has no valve, and there is no lifting pipe, the barrel being immersed in the liquid to be raised (figs. 127 and 128). There are two valves in the barrel; one, *a*, in the bottom, opens upwards; the other, *b*, is placed in the orifice of a long tube in the side of the pump.

When the piston rises (fig. 127), a vacuum being produced below it, the atmospheric pressure acts on *c*, and closes it; while the water in which the pump is immersed being forced by its own weight and that of the atmosphere, raises the valve *a*, and passes into the barrel which it completely fills. The motion of the pistons is exactly reversed when the piston descends (fig. 128). By its own weight and by the pressure upon it, the valve *a* closes, while the valve *c* opens and gives exit to the water in the barrel, which then rises to a height depending on the pressure exerted by the piston. If this amounts to a pressure of one atmosphere, water rises 34 feet in the pipe H; if it is two atmospheres water rises to 68 feet, and so on; that is, always to a height of 34 feet for a pressure of one atmosphere. The height, therefore, to which water can be raised in these pumps is not limited as it is in the friction-pump.

From what has been said, it will be seen that water only rises in the pipe H when the piston descends; there is, therefore, an intermittent flow at the end of the pipe. A more regular flow is obtained by arranging two pumps, both forcing water into the same pipe, and in such a manner that, when one piston rises, the other sinks. It is by means of such an arrangement of two pumps that air is raised to the wicks in Carcel's lamps. At the base of these lamps, and in the oil itself, are two small pumps worked by a clockwork motion, which is wound up like a clock. Such a system is also applied in fire-engines.

147. **Fire-engines.**—In a *fire-engine* water has to be forced to a great height in a continuous stream. Fig. 129 represents a section of such a pump. To the handles PQ are fixed, by means of a joint, two rods which work the pistons *m* and *n* in two brass barrels. These pumps are placed in a trough, MN, of the same metal, which is called the tank, and which is fed with water while the pump is at work. Between these two is an air-chamber R, with a lateral aperture Z, to which can be attached a long leather tube. This

tube is provided at the end with a long conical copper tube, and which has an aperture only about three-fifths of an inch diameter.

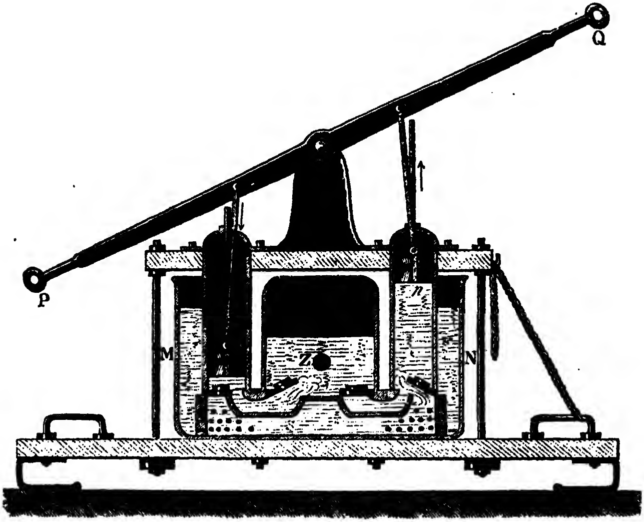

Fig. 129.

The use of the air-chamber is as follows: Although the pistons work alternately there would necessarily be some intermittence in the jet when they are at the top or at the bottom of their course. But the water, instead of being forced by the pumps directly into the ascending pipe, first passes into the reservoir R, as shown in fig. 129. Owing to the resistance in the tube and on the jet, it flows out of the reservoir more slowly than it enters. Its level rises in the reservoir, and as the air is thereby reduced in volume, its pressure increases, so that the compressed air, reacting on the water when the pistons stop, forces out the water and thus keeps up the continuity of the jet. A good fire-engine worked by eight men will raise water to a height of 100 feet.

148. **The syphon.**—The syphon is a bent tube open at both ends and with unequal legs (fig. 130). It is used in transferring liquids, especially in cases in which they are to be removed without disturbing any sediment they contain. It is worked in the following manner: The syphon is filled with some liquid, and the two ends being closed, the shorter leg is dipped in the liquid, as represented

in fig. 130; or the shorter leg having been dipped in the liquid, the air is exhausted by applying the mouth at *b*. A vacuum is thus

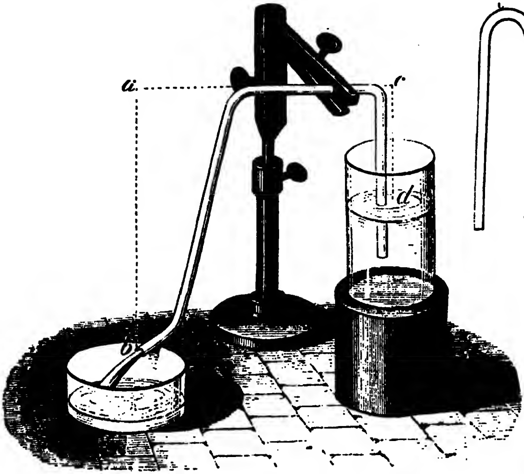

Fig. 130.

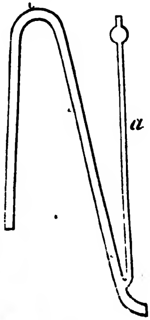

Fig. 131.

produced, the liquid in *d* rises and fills the tube in consequence of the atmospheric pressure. It will then run out through the syphon as long as the shorter end dips in the liquid.

A syphon of the form represented in fig. 131 is used where the presence of the liquid in the mouth would be objectionable. A tube, *a*, is attached to the longer branch, and it is filled by closing the end of the longer limb, and sucking at the end of *a*.

To explain this flow of water from the syphon, let us suppose it filled and the short leg immersed in the liquid. The pressure then acting on *d*, and tending to raise the liquid in the tube, is the atmospheric pressure minus the height of the column of liquid, *cd*. In like manner, the pressure on the end of the tube *b* is the weight of the atmosphere less the pressure of the column of liquid, *ab*. But as this latter column is longer than *cd*, the force acting at *b* is less than the force acting at *c*, and consequently a flow takes place proportional to the difference between these two forces. The flow will therefore be more rapid in proportion as the difference of level between the aperture *b* and the surface of the liquid in *d* is greater.

CHAPTER III.

PRESSURE ON BODIES IN AIR. BALLOONS.

149. **Archimedes' principle applied to gases.**—The pressure exerted by gases on bodies immersed in them, is transmitted equally in all directions, as has been shown by the experiment with the Magdeburg hemispheres. It therefore follows, that all which has been said about the equilibrium of bodies in liquids, applies to bodies in air; they lose a part of their weight equal to that of the air which they displace.

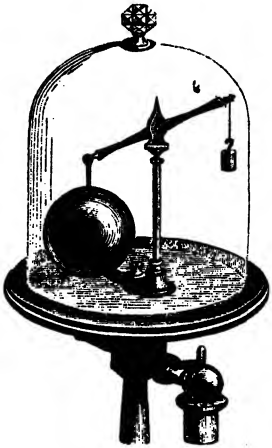

Fig. 132.

This loss of weight in air is demonstrated by means of the *baroscope*, which consists of a scalebeam, at one of whose extremities a small leaden weight is supported, and at the other there is a hollow copper sphere (fig. 132). They are so constructed that in air they exactly balance one another, but when they are placed under the receiver of the air-pump and a vacuum is produced, the sphere sinks; thereby showing that in reality it is heavier than the small leaden weight. Before the air is exhausted each body is buoyed up by the weight of the air which it displaces. But as the sphere is much the larger of the two, its weight undergoes most apparent diminution; and thus, though in reality the heavier body, it is balanced by the small leaden weight. It may be proved by means of the same apparatus that this loss is equal to the weight of the displaced air, and we may thus generalise Archimedes' principle and say, that any body plunged in any fluid, whether it be a liquid or a gas, loses part of its weight equal to the weight of the displaced fluid. Hence bodies weighed in air usually indicate too small a weight. To have an exact weight the volume of the weights and of the displaced fluid should be exactly the same, which is seldom the case. The true weight of bodies is obtained by weighing them in a vacuum.

The principle of Archimedes being thus true for bodies in air, all that has been said about bodies immersed in liquids applies to them, that is, that when a body is heavier than air it will sink, owing to the excess of its weight over the buoyancy. If it is as heavy as air, its weight will exactly counterbalance the buoyancy, and the body will float in the atmosphere. If the body is lighter than air, the buoyancy of the air will prevail, and the body will rise in the atmosphere until it reaches a layer of the same density as its own. The force of the ascent is equal to the excess of the buoyancy over the weight of the body. This is the reason why smoke, vapours, clouds, and air balloons rise in the air.

150. **Air balloons.**—*Air balloons* are hollow spheres made of some light impermeable material, which, when filled with heated air, with hydrogen gas, or with coal gas, rise in the air in virtue of their relative lightness.

They were invented by the brothers Montgolfier, of Annonay, and the first experiment was made at that place in June 1783. Their balloon was a sphere of 40 yards in circumference, and weighed 500 pounds. At the lower part there was an aperture, and a sort of boat was suspended, in which was burnt paper and straw. The heated air thus produced gradually inflated the balloon, and when it was full of expanded air, lighter than the external air, the weight of the balloon and its hot air being less than that of the air which it displaced, it soon rose to a height of more than 2,000 yards, to the great astonishment of the assembled spectators. It rapidly descended, however, the hot air it contained soon becoming cooled in the higher regions of the atmosphere.

The experiment at Annonay excited great interest all over France, and pending the repetition on a larger scale at the expense of the government, Charles, a professor of physics, constructed a smaller balloon, about 13 feet in diameter, which was filled with hydrogen instead of heated air. The use of hydrogen is very advantageous, for as it is almost 14 times less dense than air, its ascensional force is far greater than that of hot air, and it is also less dangerous, for in heating the air there is a great risk of setting fire to the balloon. Charles made an ascent in 1783 in a balloon inflated by hydrogen.

Since then, the art of ballooning has been greatly extended, and many ascents have been made. That which Gay-Lussac made in 1804 was the most remarkable for the facts with which it has enriched science, and for the height which he attained—23,000 eet

above the sea level. At this height the barometer descended to 12·6 inches, and the thermometer, which was 31° C. on the ground, was 9 degrees below zero.

In these high regions, the dryness was such on the day of Gay-Lussac's ascent, that hygrometric substances, such as paper, parchment, &c., became dried and crumpled as if they had been placed near the fire. The respiration and circulation of the blood were accelerated in consequence of the great rarefaction of the air. Gay-Lussac's pulse made 120 pulsations in a minute, instead of 66, the normal number. At this great height the sky had a very dark blue tint, and an absolute silence prevailed.

One of the most remarkable recent ascents was made by Mr. Glaisher and Mr. Coxwell, in a large balloon belonging to the latter. This was filled with 90,000 cubic feet of coal gas (sp. gr. 0·37 to 0·33); the weight of the load was 600 pounds. The ascent took place at 1 P.M. on September 5, 1861; at 1° 28′ they had reached a height of 15,750 feet, and in eleven minutes after a height of 21,000 feet, the temperature being −10·4°; at 1° 50′ they were at 26,200 feet with the thermometer at −15·2°. At 1° 52′ the height attained was 39,000 feet, and the temperature −16·0 C. At this height the rarefaction of the air was so great and the cold so intense that Mr. Glaisher fainted, and could no longer observe. According to an approximate estimation the lowest barometric height they attained was 7 inches, which would correspond to a height of 36,000 to 37,000 feet.

151. **Construction and management of balloons.**—A balloon (fig. 133) is made of long bands of silk sewed together and covered with caoutchouc varnish, which renders it air-tight. At the top there is a safety-valve closed by a spring, which the aëronaut can open at pleasure by means of a cord. A light wicker-work boat is suspended by means of cords to a net-work, which entirely covers the balloon.

A balloon of the ordinary dimensions, which can carry three persons, is about 16 yards high, 12 yards in diameter, and its volume when it is quite full is about 680 cubic yards. The balloon itself weighs 200 pounds; the accessories, such as rope and boat, 100 pounds.

The balloon is filled either with hydrogen or with coal gas. Although the latter is heavier than the former, it is generally preferred, because it is cheaper and more easily obtained. It is passed into the balloon from the gas reservoir by means of a flexible pipe

(fig. 133). It is important not to fill the balloon quite full, for the atmospheric pressure diminishes as it rises, and the gas inside expanding in consequence of its elastic force, tends to burst it. It is sufficient for the ascent if the weight of the displaced air exceeds that of the balloon by 8 or 10 pounds. And this force

Fig. 133.

remains constant so long as the balloon is not quite distended by the dilatation of the air in the interior. If the atmospheric pressure, for example, has diminished to one-half, the gas in the balloon, according to Boyle and Mariotte's law, has doubled its volume. The volume of the air displaced is therefore twice as great; but since its density has become only one-half, the weight, and consequently

the upward buoyancy, are the same. When once the balloon is completely dilated, if it continue to rise, the force of the ascent decreases, for the volume of the displaced air remains the same, but its density diminishes, and a time arrives at which the buoyancy is only equal to the weight of the balloon. The balloon can now only take a horizontal direction, carried by the currents of air which prevail in the atmosphere. The aëronaut knows by the barometer whether he is ascending or descending; and by the same means he determines the height which he has reached. A long flag fixed to the boat would indicate, by the position it takes either above or below, whether the balloon is descending or ascending.

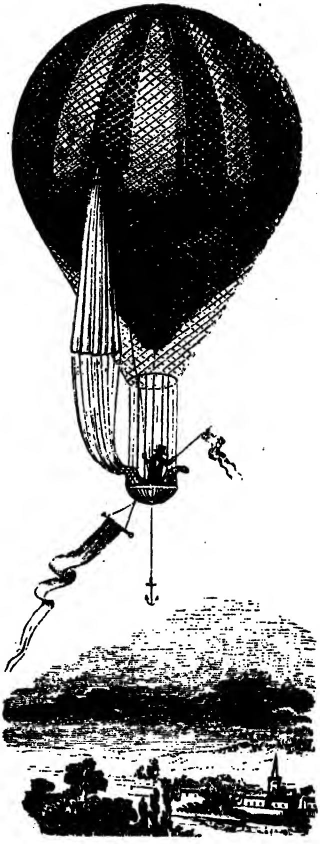

Fig. 134.

When the aëronaut wishes to descend, he opens the valve at the top of the balloon by means of the cord, which allows gas to escape, and the balloon sinks. If he wants to descend more slowly, or to rise again, he empties out bags of sand, of which there is an ample supply in the car. The descent is facilitated by means of a grappling iron fixed to the boat. When once this is fixed to any obstacle, the balloon is lowered by pulling the cord.

The only practical applications which air balloons have hitherto had, have been in military reconnoitring. At the battle of Fleurus in 1794, a captive balloon, that is, one held by a cord, was used, in which there was an observer who reported the movements of the enemy by means of signals. At the battle of Solferino the move-

ments and dispositions of the Austrian troops were watched by a captive balloon; and in the war in America balloons were frequently used; while the part which they played in the siege of Paris is still fresh in all memories. Many ascents have recently been made by Mr. Glaisher for the purpose of making meteorological observations in the higher regions of the atmosphere. Air balloons can only be truly useful when they can be guided, and as yet all attempts made with this view have completely failed. There is no other course at present than to rise in the air, until there is a current which has more or less the desired direction.

152. **Parachute.**—The object of the parachute is to allow an aëronaut to leave the balloon, by giving him the means of lessening

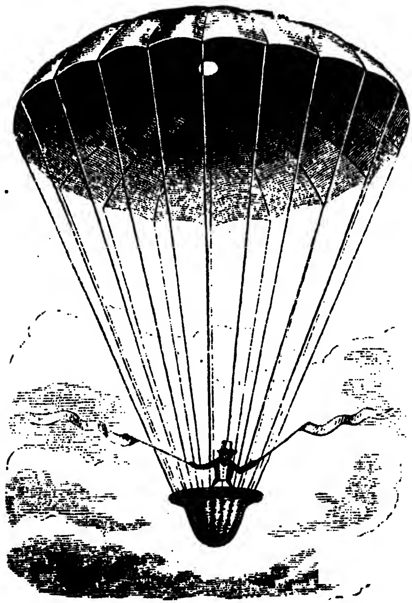

Fig. 135.

the rapidity of his descent. It consists of a large circular piece of cloth (fig. 135) about 16 feet in diameter, and which by the resistance of the air spreads out like a gigantic umbrella. In the centre there is an aperture, through which the air, compressed by

the rapidity of the descent, makes its escape; for otherwise oscillations might be produced, which, when communicated to the boat, would be dangerous.

In fig. 134 there is a parachute attached to the network of the balloon by means of a cord, which passes round a pulley, and is fixed at the other end to the boat. When the cord is cut, the parachute sinks, at first very rapidly, but more slowly as it becomes distended, as represented in the figure.

BOOK IV.

ACOUSTICS.

CHAPTER I.

PRODUCTION, PROPAGATION, AND REFLECTION OF SOUND.

153. **Object of acoustics.**—The study of sounds, and that of the vibrations of elastic bodies, form the object of *acoustics.*

Music considers sounds with reference to the pleasurable feelings they are calculated to excite. Acoustics is concerned with the questions of the production, transmission, and comparison of sounds. To which may be added the physiological question of the perception of sounds.

Sound is a peculiar sensation excited in the organ of hearing by the vibratory motion of bodies, when this motion is transmitted to the ear through an elastic medium.

Take for instance the string of a musical instrument, when it is pulled or sounded by a bow (fig. 136). When this is pulled aside from the position *acb*, where it is at rest, to the position *adb*, all the

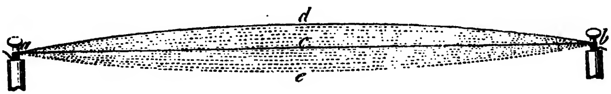

Fig. 136.

points being more or less out of their position of equilibrium, when the string is left to itself, owing to its elasticity it tends to revert to its original position *acb*. In virtue, however, of its acquired velocity, it passes beyond it as far as *aeb*, all the points being then virtually as far out of their position of rest as they were at *adb*. But as the elasticity still continues to act, not merely does the string revert to its original position, but it again passes beyond it, and so

on, the amplitude of its path becoming smaller and smaller, as represented by the dotted lines in the figure, until it ultimately reverts to its original state of equilibrium. Hence each point of the string makes a backward and forward, or vibratory motion, like that of the pendulum. The passage from the position *adb* to *aeb*, and back to *adb*, is called a complete *vibration* or *oscillation*; the passage from *adb* to *aeb*, or from *aeb* to *adb*, is a *semi-vibration* or *semi-oscillation*.

Any body which vibrates and yields a sound, is called a *sonorous* or *sounding body*. The vibrations of sounding bodies are generally too rapid to be counted or even distinctly seen. Yet they may be rendered evident in a variety of ways. Thus, if a tolerably large bell jar be made to sound by striking it with the finger, and a small ivory ball suspended by a thread be approached to it, the ball will be observed to receive a series of rapid shocks from the sides of the bell, showing that it is in a state of vibration. Or, if a plate of metal be fixed horizontally at one end, and sand be strewed over it, when the plate is made to vibrate by briskly moving a violin bow against the edge, the sand becomes violently agitated, which is obviously due to the vibrations of the plate.

154. **Propagation of sound in the air. Sound waves.**—After having ascertained that when a body emits a sound, its molecules are in a state of vibration, it remains to explain how these are transmitted to the ear to produce the sensation of sound. Sound always requires for its transmission an elastic medium, which at one end is in contact with the sounding body, and at the other with the organ of hearing. Air is the ordinary medium through which sound is transmitted. As air is very mobile, compressible, and elastic, its molecules in contact with different points of the sounding body acquire movements similar to those of these points ; they go and come with these points, so that each molecule of air in contact with the body is pushed forward by it in the direction of the sound. and returns, having communicated its motion to the next molecule ; this then acts in the same manner on the next molecule, and so on to the molecules in contact with the *tympanum* or *drum*. This is the name given to a membrane placed at the end of the auditory canal of the ear, and which receives the vibrations of the air, which it transmits by a series of small bones and liquids to the acoustic nerve, and thence to the brain, which finally perceives the sensation of sound.

At each impulse imparted by a sounding body to the molecules of air in contact with it, these molecules pressing in turn upon t

succeeding ones, a condensed part is produced in the air to a certain distance which is called the *condensed wave*; then, when the vibrating body reverts to its original position, the molecules nearest to it follow it in its motion, so that there is formed in the air a rarefied part which follows the condensed wave, and which is called the *rarefied wave.* A condensed and a rarefied wave together form a sound wave. A sounding body is a centre from which these waves are emitted all round it in the form of continually increasing spheres, and thus it is that sound is propagated by a body in all directions. Fig. 137 furnishes a rough illustration of this process. If a stone is thrown into still water, there are found round the point where it falls a series of concentric waves, which continually increase, and

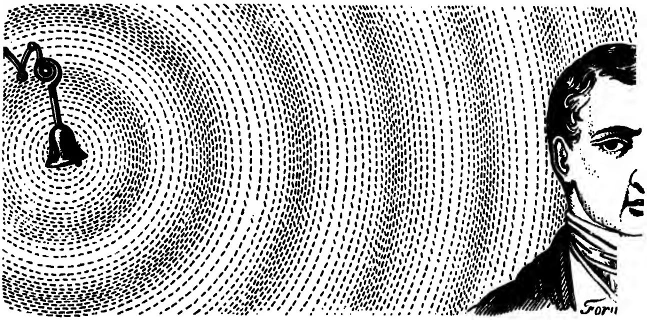

Fig. 137.

which give an idea of the propagation of sound waves in the air.

In the case of very intense sounds, the disturbance communicated to the air in the form of sound waves may be very considerable. Thus the waves produced by thunder, by the report of cannon, and by gunpowder explosion, are frequently powerful enough to break whole panes of glass.

155. **Coexistence of sound waves.**—It is to be observed that several sounds may be propagated in air without destroying each other. Thus in the most complicated orchestral music, a person with a practised ear can readily follow the sound of each instrument. Yet a loud sound interferes with a weak one; thus the sound of a drum overpowers the human voice. Sounds also which are too weak to be distinctly heard accumulate upon each other, and produce a confused sound, which becomes perceptible to the ear.

Such is the cause of the murmuring of water, the rustling of leaves in woods, and the dashing of waves against the shores.

156. **Sound is not propagated in vacuo.**—The vibrations of elastic bodies can only produce the sensation of sound in us, by the intervention of a medium interposed between the ear and the sonorous body, and vibrating with it. This medium is usually the air, but all gases, vapours, liquids, and solids also transmit sounds.

The following experiment shows that the presence of a ponderable medium is necessary for the propagation of sound. A tolerably large glass globe (fig. 138), provided with a stopcock, has a small bell suspended in the interior by a thread. A vacuum having been created in the globe by means of the air-pump, no sound is emitted when the globe is shaken, though the clapper may be seen to strike against the bell; but if air, or any other gas or vapour, be admitted, sound is distinctly heard each time the globe is agitated.

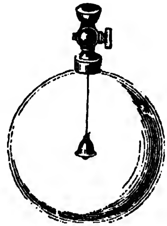

Fig. 138.

The experiment may also be made by placing a small metallic bell, which is continually struck by a small hammer by means of clockwork, or an ordinary musical box, under the receiver of the air-pump. As long as the receiver is full of air at the ordinary pressure, the sound is transmitted; but, in proportion as the air is exhausted, the sound becomes feebler, and is imperceptible in a vacuum.

To ensure the success of the experiment, the bellwork or musical box must be placed on wadding; for otherwise the vibrations would be transmitted to the air through the plate of the machine.

157. **Propagation of sound in liquids and solids.**—Sound is also propagated in liquids. When two bodies strike against each other under water, the shock is distinctly heard; and a diver at the bottom of the water can hear the sound of voices on the bank.

The conductibility of solids is such, that the scratching of a pen at the end of a long wooden rod is heard at the other end. In like manner if a person speaks with a low voice at the end of a pine rod, 25 to 30 yards long, he is heard by a person whose ear is applied against the other end, while a person who is near, hears nothing. The earth conducts sound so well, that at night, when the ear is applied to the ground, the steps of horses or any other noise at great distances is heard.

158. **Velocity of sound in air.**—Numerous phenomena show

that sound requires a certain time to pass from one place to another. Thus, if we pay attention to a woodman felling trees at a distance, we see the axe fall in silence, and only hear the sound a moment afterwards. In like manner, when a gun is fired, the report is heard after the flash of light. Thunder, too, is only heard some time after lightning, although in the cloud both thunder and lightning are heard simultaneously.

The velocity of sound was determined experimentally by the members of the Bureau of Longitude of Paris in June 1822, during the night. A cannon was placed on a hill at Montlhéry near Paris, and another on a plateau near Villejuif. The distance of the two places was carefully measured, and was found to be 61,045 feet, and a gun was fired at each station twelve successive times at intervals of 10 minutes (fig. 139). Observers placed near the pieces noted

Fig 139.

by means of accurate and delicate watches, the time which elapsed between the appearance of the flash and the hearing the sound at the opposite station; and the mean of the observations gave the number 54·6 seconds. This was just the time which the sound required to travel from one station to the other; for we shall afterwards see that the velocity of light is such that the time it requires to traverse the above distance is inappreciable. Hence by a simple calculation we find that sound travels 1,118 feet in a second.

The above observations were made when the air was at a temperature of 16°. At a lower temperature the velocity of sound is less.

From some accurate experiments made by the above method near Amsterdam, the velocity of sound is taken at 1,093 feet per second in dry air at zero. Its velocity increases about 2 feet per second for every degree centigrade. So that at 15° C., which is the ordinary temperature, the velocity of sound is 1,120 feet per second.

A knowledge of the velocity of sound enables us to measure distances. Thus, suppose we want to know the distance at which a gun is fired, of which we only hear the report 15 seconds after seeing the flash. As sound travels at 1,120 feet in a second, it must traverse 16,800 feet in the time mentioned, and this would be the distance at which the gun was fired. In the same manner we may calculate the depth of a well from the number of seconds which elapses between the moment at which a stone falls into it and that at which the sound is produced. The calculation is, however, a little more complicated, for the time which the body requires in falling has to be taken into account.

The velocity of sound is not the same in different gases; it is greater in those which are less dense. Dulong found the velocity at zero to be 846 feet per second for carbonic acid, 1,040 feet in oxygen, and 1,093 in air, 1,106 in carbonic oxide, and 4,163 feet in hydrogen.

The velocity of sound is the same in air for all sounds, whether strong or weak, grave or acute.

For this reason the tune played by a band is heard at a great distance without alteration, except in intensity, which could not be the case if some sounds travelled more rapidly than others.

159. **Velocity of sound in liquids and in solids.**—We have already seen that liquids conduct sound; they even conduct it better than gases. The velocity of sound in water was investigated in 1827 by Colladon and Sturm. They moored two boats at a known distance in the Lake of Geneva. The first supported a bell immersed in water, and a bent lever provided at one end with a hammer which struck the bell, and at the other with a lighted wick, so arranged that it ignited some powder the moment the hammer struck the bell. To the second boat was affixed an ear-trumpet, the bell of which was in water, while the mouth was applied to the ear of the observer, so that he could measure

the time between the flash of light, and the arrival of sound by the water. By this method the velocity was found to be 4,708 feet in a second at the temperature 8°, or four times as great as in air.

That sound travels more rapidly in solids than in air is easily shown. If a person holds his ear against one end of a tolerably long iron bar, while another person gives a hard blow at the other end, two distinct sounds are heard; the first transmitted by the metal, and the other transmitted by the air. The velocity of sound in iron is 16,802 feet in a second; in copper, 11,606; in oak, 10,900; and in fir, 15,218 feet.

160. **Reflection of sound.**—We have seen that sound is propagated in air by means of spherical waves, alternately condensed and rarefied, and which are developed about it in all directions. So long as these sonorous waves are not obstructed in their motion, they are propagated in the form of concentric spheres; but when they meet with an obstacle, they follow the general law of elastic bodies; that is, they are repelled like an ivory ball which strikes against a wall; they return upon themselves, forming new concentric waves, which seem to emanate from a second centre on the other side of the obstacle. This phenomenon constitutes the *reflection of sound.*

The reflection of sound, or rather of sound waves, follows the same laws as the reflection of heat and of light, which we shall subsequently have to explain.

161. **Echoes and resonances.**—An *echo* is the repetition of a sound in the air, caused by its reflection from some more or less distant obstacle. Thus, if a few words are loudly spoken at a certain distance from a wood, a rock, or a building, it usually happens that, after a brief interval, the same phrase is heard repeated, as if spoken in the distance by another person; these are the sound waves, which are reflected by the obstacle. There must, however, be a certain distance between the place at which the sound is produced and that at which it is heard.

A very sharp quick sound can produce an echo when the reflecting surface is 55 feet distant; but for articulate sounds at least double that distance is necessary, for it may be easily shown that no one can pronounce or hear distinctly more than five syllables in a second. Now, as the velocity of sound at ordinary temperatures may be taken at 1,125 feet in a second, in a fifth of that time sound would travel 225 feet. If the reflecting surface is 112·5 feet distant, sound would travel through 225 feet in going and returning. The

time which elapses between the articulated and the reflected sound would, therefore, be a fifth of a second, the two sounds would not interfere, and the reflected sound would be distinctly heard. A person speaking with a loud voice in front of a reflecting surface at the distance of 112·5 feet can only distinguish the last reflected syllable : such an echo is said to be *monosyllabic*. If the reflector were at a distance of two or three times 112·5 feet, the echo would be *dissyllabic*, *trisyllabic*, and so on.

Multiple echoes are those which repeat the same sound several times ; this is the case when two opposite surfaces (for example, two parallel walls) successively reflect sound. There are echoes which repeat the same sound 20 or 30 times. An echo in the château of Simonetta, in Italy, repeats a sound 30 times. At Woodstock there is one which repeats from 17 to 20 syllables. Near Verdun is an echo formed by two parallel towers, at a distance from each other of about 164 feet. A person placing himself between them, and speaking a word with a loud voice, hears it repeated a dozen times. Echoes usually modify sound ; some repeat it with noise ; others with a mocking, laughing tone, or a plaintive accent.

We have seen that when the distance at which a sound is reflected is 112 feet an echo is produced ; and the question may be asked, what happens when the distance is less than this ? As the sound has then a smaller distance to traverse, both in going and coming, than 112 feet, it follows that the reflected sound is added to the directly spoken one. They cannot be heard separately, but the sound is strengthened. This is what is called *resonance*, and its effects are so much the more marked the more elastic are the surfaces from which the sound is reflected. In uninhabited houses, where there is no furniture, the walls, the flooring, and the ceiling readily vibrate, and we all know how the noise of footsteps and the sound of the voice then resound. Tapestry and hangings, which are not elastic, *deaden* the sound.

As the laws of the reflection of sound are the same as those of light and heat, curved surfaces produce *acoustic foci*, like the luminous and calorific foci produced by concave reflectors. If a person standing under the arch of a bridge speaks with his face turned towards one of the piers, the sound is reproduced near the other pier with such distinctness that a conversation can be kept up in a low tone, which is not heard by any one standing in the intermediate spaces.

There is a square room with an elliptical ceiling, on the ground-floor of the Conservatoire des Arts et Métiers, in Paris, which presents this phenomenon in a remarkable degree when persons stand in the two foci of the ellipse.

It is not merely by solid surfaces, such as walls, rocks, etc., that sound is reflected. It is also reflected by clouds, and on passing into a layer of air of greater density than its own; it is also further reflected by the vesicles of mist. When the weather is foggy, sounds undergo innumerable partial reflections, and are rapidly destroyed.

Whispering galleries are formed of smooth walls, having a continuous curved form. The mouth of the speaker is presented at one point, and the ear of the hearer at another and distant point. In this case, the sound is successively reflected from one point to the other until it reaches the ear.

Different parts of the earth's surface are unequally heated by the sun, owing to the shadows of trees, evaporation of water, and other causes, so that in the atmosphere there are numerous ascending and descending currents of air of different density. Whenever a sonorous wave passes from a medium of one density into another it undergoes partial reflection, which, though not strong enough to form an echo, distinctly weakens the direct sound. This is doubtless the reason, as Humboldt remarks, why sound travels further at night than at daytime; even in the South American forests, where the animals, which are silent by day, fill the atmosphere in the night with thousands of confused sounds.

162. **Causes which influence the intensity of sound.**—Many causes modify the force or the *intensity* of the sound. These are, the distance of the sonorous body, the amplitude of the vibrations, the density of the air at the place where the sound is produced, the direction of the currents of air, and, lastly, the proximity of other sonorous bodies.

i. *The intensity of sound is inversely as the square of the distance of the sonorous body from the ear.* This law has been deduced by calculation, but it may be also demonstrated experimentally. Let us suppose several sounds of equal intensity, for instance, bells of the same kind, struck by hammers of the same weight, falling from equal heights. If four of these bells are placed at a distance of 20 yards from the ear, and one at a distance of 10 yards, it is found that the single bell produces a sound of the same intensity

as the four bells struck simultaneously. Consequently, for double the distance, the intensity of the sound is only one-fourth.

The distance at which sounds can be heard depends on their intensity. The report of a volcano at St. Vincent was heard at Demerara, 300 miles off, and the firing at Waterloo was heard at Dover.

ii. *The intensity of the sound increases with the amplitude of the vibrations of the sonorous body.* The connection between the intensity of the sound and the amplitude of the vibrations, is readily observed by means of vibrating cords. For if the cords are somewhat long the oscillations are perceptible to the eye, and it is seen that the sound is feebler in proportion as the amplitude of the oscillations decreases.

It is for the same reason that the dying sound of the last blows of a bell become gradually feebler, until they are ultimately extinguished.

iii. *The intensity of sound depends on the density of the air in the place in which it is produced.* As we have already seen (156), when an alarum moved by clockwork is placed under the bell-jar of the air-pump, the sound becomes weaker in proportion as the air is rarefied.

In hydrogen, which is about $\frac{1}{14}$th the density of air, sounds are much feebler, although the pressure is the same. In carbonic acid, on the contrary, which is half as heavy again as air, sounds are more intense. On high mountains, where the air is much rarefied, it is necessary to speak with some effort in order to be heard, and the discharge of a gun produces only a feeble sound. During a severe frost, sounds are heard at a greater distance, because air is then more dense and more homogeneous; and country people will often predict the weather from the sound of the village bell. For the sound is modified by the presence of moisture, which alters the elasticity and the density.

iv. *The intensity of sound is modified by the motion of the atmosphere and the direction of the wind.* In calm weather sound is always better propagated than when there is wind; in the latter case, for an equal distance, sound is more intense in the direction of the wind than in the contrary direction.

v. Lastly, *sound is strengthened by the proximity of a sonorous body.* A string made to vibrate in free air and not near a sounding body has but a very feeble sound; but when it vibrates above a sounding-box, as in the case of the violin, guitar, or violoncello,

its sound is much more intense. This arises from the fact that the box and the air which it contains vibrate in unison with the string. Hence the use of sounding-boxes in stringed instruments.

163. **Influence of tubes on the transmission of sound.**—The diminution in the intensity of sound with the distance is due to the fact, that the sound waves are propagated in the form of continually increasing spheres; and it may indeed be proved geometrically, that since sound is thus transmitted, its intensity must be inversely as the square of the distance. If, however, the sound is sent through a long tube, the waves are propagated in only one direction, and sound can be transmitted to great distances without appreciable alteration. M. Biot found that in one of the Paris water pipes, 1,040 yards long, the voice lost so little of its intensity, that a conversation could be kept up at the ends of the tube in a very low tone; so much so, that in order not to be heard, it was necessary, as Biot expressed it, *not to speak at all.* The weak-

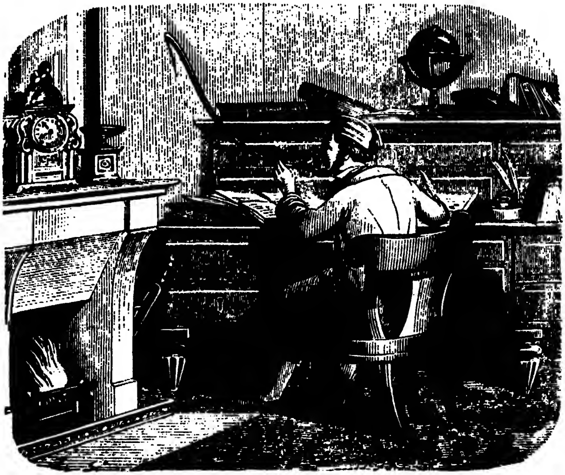

Fig. 140.

ening of sound becomes, however, perceptible in tubes of large diameter, or where the sides are rough.

This property of transmitting sounds was first applied in England for *speaking tubes,* which are used in hotels and large estab-

lishments for transmitting orders. They consist of caoutchouc tubes of small diameter, provided at each end with an ivory or bone mouthpiece, and passing from one room to another. If a person speaks at one end of the tube, he is distinctly heard by a person applying his ear (fig. 140) at the other end.

One of the most important applications of acoustical principles is the *Stethoscope.* It consists of a cylinder of hard wood about a foot long and $1\frac{1}{4}$ inch broad at one end, and in which a longitudinal passage is bored. One end of the stethoscope is held against the diseased part of the body, and the ear is held against the other. The practised physician can detect the existence of internal cavities by the peculiar sound emitted, and which is strengthened by resonance.

164. **Speaking trumpet.**—These instruments are based both on the reflection of sound, and on its conductibility in tubes.

The *speaking trumpet,* as its name implies, is used to render

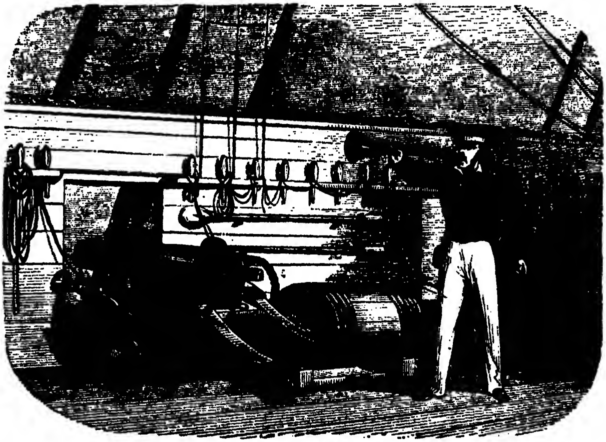

Fig. 141.

the voice audible at great distances. It consists of a slightly conical tin or brass tube (fig. 141), very much wider at one end (which is called the *bell*), and provided with a mouthpiece at the other. The larger the dimensions of this instrument the greater is the distance at which the voice is heard. Its action is usually ascribed to the successive reflections of sonorous waves from the

sides of the tube, by which the waves tend more and more to pass in a direction parallel to the axis of the instrument. By means of the speaking trumpet, the word of command can be heard on board ship above the noise of the waves.

165. **Ear trumpet.**—The *ear trumpet* is used by persons who are hard of hearing. It is essentially an inverted speaking trumpet, and consists of a conical metallic tube, one of whose extremities, terminating in a *bell*, receives the sound, while the other end is introduced into the ear (fig. 142). This instrument is the reverse

Fig. 142.

of the speaking trumpet. The bell serves as mouthpiece; that is, it receives the sounds coming from the mouth of the person who speaks. These sounds are transmitted by a series of reflections to the interior of the trumpet, so that the waves which would become greatly developed, are concentrated on the auditory apparatus, and produce a far greater effect than divergent waves would have done.

In man and many animals the external ear is a trumpet which receives the sound waves. In some animals this part of the auditory apparatus is long and flexible, so that the animal can thus easily recognise the direction from which the sound proceeds.

CHAPTER II.

MUSICAL SOUND. PHYSICAL THEORY OF MUSIC.

165*a*. **Difference between musical sound and noise.**—Sounds are distinguished from *noises*. Sound properly so called, or *musical sound*, is that which produces a continuous sensation, and the musical value of which can be determined : while noise is either a sound of too short a duration to be determined, like the report of a cannon, or else it is a confused mixture of many discordant sounds, like the rolling of thunder, or the noise of the waves. Nevertheless, the difference between sound and noise is by no means precise. Savart has shown that there are relations of height in the case of noise, as well as in that of sound, and there are said to be certain ears sufficiently well organised to determine the musical value of the sound produced by a carriage rolling on the pavement.

166. **Characteristics of musical sounds.**—Musical tones have three leading qualities, namely *pitch*, *intensity*, and *timbre* or *colour*.

i. The *pitch* or *height* of a musical tone is determined by the number of vibrations per second yielded by the body producing the tone.

ii. The *intensity* or *loudness* of the tone depends on the *extent* of the vibrations. It is greater when the extent is greater, and less when it is less. It is, in fact, nearly or exactly proportional to the square of the extent or amplitude of the vibrations which produce the tone.

iii. The *timbre* is that peculiar quality of tone which distinguishes a note when sounded on one instrument, from the same note when sounded on another. Thus when the C of the treble stave is sounded on a violin, and on a flute, the two notes will have the same pitch, that is, are produced by the same number of vibrations per second, and they may have the same intensity, and yet the two tones will have very distinct qualities, that is, their timbre is different.

167. **Limit of perceptible sounds.**—Savart, a French physicist, was the first to determine the limit of the number of vibrations which the ear could perceive. By the aid of apparatus which he invented, he ascertained that the deepest sounds are produced

by 16 vibrations in a second. If the number of vibrations is less, no sound is heard. The same physicist found that the highest sound which the ear can perceive corresponds to 48,000 vibrations in a second. Between these two limits it will be seen what an enormous quantity of sounds may be produced and perceived. Yet the sounds used in music, and more especially in singing, are comprised within much narrower limits. Thus the human voice has been compared with the sound produced by instruments, the number of whose vibrations could be ascertained; and it has been found that the lowest notes of a man's voice are made by 190 vibrations in a second, and the highest notes by 678. The lowest note of a woman's voice corresponds to 572 vibrations, and the highest to 1,606.

168. **Musical scale. Gamut.**—The human ear can distinguish among several sounds not merely which is the highest, or the lowest, but it can also estimate the relations which exist between the numbers of vibrations corresponding to each of these sounds. Not, indeed, that we can say whether one sound produces two or three times as many vibrations as another; but whenever the number of vibrations of two successive or simultaneous sounds are in a simple ratio, these sounds excite in us an agreeable sensation, which varies with the ratio of the vibrations of the two sounds, and which the ear can readily estimate. Hence results a series of sounds characterised by relations, which have their origin in the nature of our organisation, and which constitute what is called the *musical scale.*

In this series the sounds are reproduced in the same order, in periods of seven, each period constituting a *gamut*; and the seven sounds or *notes* of each gamut by the names C, D, E, F, G, A, B, or by *ut* or *do*, re, mi, fa, sol, la, si. The first six of these letters are the first syllables of the lines of a hymn which was sung by the chorister children to St. John, their patron saint, when they prayed to be freed from hoarseness; and the word *si* is formed of the first letter of St John's name.

Ut queant laxis	**re**sonare fibris
Mira gestorum	**fa**muli tuorum
Solve polluti	**la**bii reatum
S ancte	I oannes.

The word gamut is derived from gamma, the third letter of the Greek alphabet, because Guido d'Arezzo, who first (in the eleventh

century) represented notes by points placed on parallel lines, denoted these lines by letters, and chose the letter gamma to designate the first line.

If we agree to represent by 1 the number of vibrations of the fundamental note C or *do* of the gamut, that is to say, of the deepest note; experiment shows that the numbers of vibrations of the other notes of the scale are those given in this table :—

C	D	E	F	G	A	B	C
do	re	mi	fa	sol	la	si	do
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

This table does not give the absolute numbers of the vibrations of the various notes, but only their relative numbers. Knowing the absolute number of vibrations of the fundamental C, we may deduce those of the other notes by multiplying them by $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$ . . . or 2 respectively; and we thus find that at the octave (169), the number of vibrations is double that of the fundamental note.

The scale may be continued by taking the octaves of these notes namely, c, d, e, f, g, a, b, and again the octaves of these last, and so forth.

169. **Intervals.**—An *interval* is the ratio of one sound to another, that is, the relation between the numbers of vibrations which produce these sounds.

The interval between two consecutive notes of the gamut is called a *second*; such as the interval from *do* to *re*, from *re* to *mi*, from *mi* to *fa*, and so on.

If between any two notes which are compared, there are one, two, three, four, five, or six intermediate notes, these intervals are called respectively, a *third*, a *fourth*, *fifth*, *sixth*, *seventh*, and *octave*. Thus the interval from C to E is a third, that from C to F a fourth, from C to G a fifth, from C to A a sixth, and from C to B a seventh, and from C to *c* an octave.

Although two or more notes may be separately musical, it does not follow that, when sounded together, they produce a pleasant sensation. When the ear can distinguish without fatigue the ratio between two sounds, which is the case when the ratio is simple, the accord or co-existence of these two sounds forms a *consonance*; but if the number of vibrations is in a complicated ratio the ear is unpleasantly affected and we have *dissonance*.

The simplest concord is *unison*, in which the numbers of vibra-

tions are equal; then comes the octave, in which the number of vibrations of one sound is double that of the other; then the fifth, where the ratio of the sounds is as 3 to 2; the fourth, of which the ratio is 4 to 3; and, lastly, the third, where the ratio is 5 to 4.

If three notes are sounded together they are concordant, when the numbers of their vibrations are as 4 : 5 : 6. Three such notes form a *harmonic triad*, and if sounded with a fourth note, which is the octave of the lowest, they constitute what is called a *major chord.* Thus C, E, G form a major triad, G, B, *d* form a major triad, and F, A, *c* form a major triad. C, G, and F have, for this reason, special names, being called respectively, the *tonic*, *dominant*, and *sub-dominant*, and the three triads the *tonic*, *dominant*, and *sub-dominant* triads or chords respectively.

If, however, the ratio of any three notes is as 10 : 12 : 15, the three sounds are slightly dissonant, but not so much so as to disqualify them from producing a pleasant sensation, at least under certain circumstances. When these three notes and the octave to the lower are sounded together they constitute what in music is called a *minor chord.*

The intervals between the notes in the scale are—

C to D $\frac{9}{8}$.	G to A $\frac{10}{9}$.
D to E $\frac{10}{9}$.	A to B $\frac{9}{8}$.
E to F $\frac{16}{15}$.	B to C $\frac{16}{15}$.
F to G $\frac{9}{8}$.	

It will be seen that there are here three kinds of intervals; the interval $\frac{9}{8}$ is called a *major tone*, and that of $\frac{10}{9}$ a *minor tone*; the relation between the major and the minor tone is $\frac{9}{8} : \frac{10}{9} = \frac{81}{80}$, and is called a *comma.* The interval $\frac{16}{15}$ is called a *major semitone.* The major scale is formed of the following succession of intervals: a major tone, a minor tone, a major semitone, a major tone, a minor tone, a major tone, and a major semitone. This succession it is which constitutes the scale; the key note, or the tonic, may have any number of vibrations; but once its height is fixed, that of the other notes are always in the above ratio.

170. **On semitones and on scales with different key notes.**—It is found convenient for the purposes of music to introduce notes intermediate to the seven notes of the gamut; this is done by increasing or diminishing those notes by an interval of $\frac{25}{24}$, which is called a ***minor semitone.*** When a note (say C) is increased by

this interval, it is said to be sharpened, and is denoted by the symbol C♯, called 'C sharp;' that is $C\sharp \div C = \frac{25}{24}$. When it is decreased by the same interval, it is said to be flattened, and is represented thus—B♭, called 'B flat;' that is, $B \div B\flat = \frac{25}{24}$. If the effect of this be examined, it will be found that the number of notes in the scale from C up to *c* has been increased from seven to twenty-one notes, all of which can be easily distinguished by the ear. Thus, reckoning C to equal 1, we have—

C	C♯	D♭	D	D♯	E♭	E	etc.
1	$\frac{25}{24}$	$\frac{27}{25}$	$\frac{9}{8}$	$\frac{75}{64}$	$\frac{6}{5}$	$\frac{5}{4}$	etc.

Hitherto we have made the note C the tonic or *key note*. Any other of the twenty-one distinct notes above-mentioned, e.g. G, or F, or C♯, etc. may be made the key note, and a scale of notes constructed with reference to it. This will be found to give rise in each case to a series of notes, some of which are identical with those contained in the series of which C is the key note, but most of them different. And of course the same would be true for the minor scale as well as for the major scale, and indeed for other scales, which may be constructed by means of the fundamental triads.

171. **On musical temperament.**—The number of notes that arise from the construction of the scales described in the last article is enormous; so much so as to prove quite unmanageable in the practice of music; and particularly for music designed for instruments with fixed notes, such as the pianoforte. Accordingly it becomes practically important to reduce the number of notes, which is done by slightly altering their just proportions. This process is called *temperament*. By tempering the notes, however, more or less dissonance is introduced, and accordingly several different systems of temperament have been devised for rendering this dissonance as slight as possible. The system usually adopted —at least in intention—is called the system of *equal temperament*. It consists in the substitution between C and *c* of eleven notes at equal intervals, each interval being, of course, the twelfth root of 2, or 1·05946. By this means the distinction between the semitones is abolished, so that, for example, C♯ and D♭ become the same note. The scale of twelve notes thus formed is called the *chromatic scale*. It of course follows that major triads become slightly dissonant. Thus, in the diatonic scale, if we reckon C to be 1, E is denoted by 1·25000, and G by 1·50000. On the system of equal

temperament if C is denoted by 1, E is denoted by 1·25992 and G by 1·49831.

172. **The number of vibrations producing each note. The tuning fork.**—Hitherto we have denoted the number of vibrations corresponding to the note C by *m*, and have not assigned any numerical value to that symbol. In the theory of music it is usual to assign 256 double vibrations to the middle C. This, however, is arbitrary. An instrument is in tune provided the intervals between the notes are correct, when C is yielded by any number of vibrations per second not differing much from 256. Moreover, two instruments are in tune with one another if, being separately in

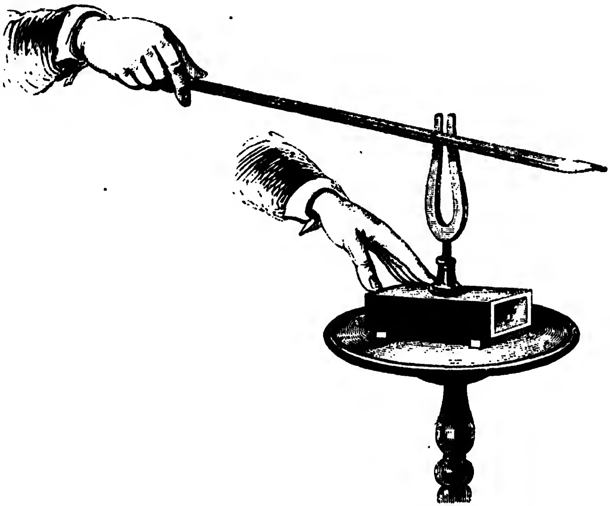

Fig. 143.

tune, they have any one note, for instance, C, yielded by the same number of vibrations. Consequently, if two instruments have one note (say C) in common, they can then be brought into tune jointly, by having their remaining notes separately adjusted with reference to that fundamental note. A tuning fork is an instrument yielding a constant sound, and is used as a standard for tuning musical instruments. It consists of an elastic steel rod, bent as represented in fig. 143. It is made to vibrate either by drawing a bow across the ends, or by striking one of the legs against a hard body, or by

rapidly separating the two legs by means of a steel rod, as shown in the figure. The vibration produces a note which is always the same for the same tuning fork. The note is strengthened by fixing the tuning fork on a box open at one end, called a *resonance box.*

It has been remarked for some years that not only has the pitch of the tuning fork, that is, *concert pitch,* been getting higher in the large theatres of Europe, but also that it is not the same in London, Paris, Vienna, Milan, etc. This is a source of great inconvenience both to composers and singers, and a commission was appointed to establish in France a tuning fork of uniform pitch, and to prepare a standard which would serve as an invariable type. In accordance with the recommendations of that body, a *normal tuning fork* has been established, which is compulsory on all musical establishments in France, and a standard has been deposited in the Conservatory of Music in Paris.

It performs 870 single vibrations per second, and gives the standard note *a*, or the *a* in the treble stave. Consequently, with reference to this standard, the middle C would result from 261 double vibrations per second.

173. **On compound musical tones and harmonics.**—When any given note (say C) is sounded on most musical instruments, not that tone alone is produced, but a series of tones, each being of less intensity than the one preceding it. If C, which may be called the *primary* tone, is denoted by unity, the whole series is given by the numbers 1, 2, 3, 4, 5, 6, 7, etc.; in other words, first the primary C is sounded, then its octave becomes audible, then the fifth to that octave, then the second octave, then the third, fifth, and a note between the sixth and seventh to the second octave, and so on. These secondary tones are called the *harmonics* of the primary *tone.* Though feeble in comparison with the primary tone, they may, with a little practice, be heard, when the primary tone is produced on most musical instruments; when, for instance, one of the lower notes is sounded on the pianoforte. Helmholtz's researches show that the different timbre or quality of the sounds yielded by different musical instruments is due to the different intensities of the harmonics which accompany the primary tones of those sounds. The leading results of these researches may be thus stated:

i. Simple tones, as those produced by a tuning fork with a resonance box, and by wide covered pipes, are soft and agreeable without any roughness, but weak, and in the deeper notes dull.

ii. Musical sounds accompanied by a series of harmonics, say up to the sixth, in moderate strength are full and musical. In comparison with simple tones they are grander, richer, and more sonorous. Such are the sounds of open organ pipes, of the pianoforte, etc.

iii. If only the uneven harmonics are present, as in the case of narrow covered pipes, of pianoforte strings struck in the middle, clarionets, etc., the sound becomes indistinct; and when a greater number of harmonics are audible the sound acquires a nasal character.

iv. If the harmonics beyond the sixth and seventh are very distinct, the sound becomes sharp and rough. If less strong the harmonics are not prejudicial to the musical usefulness of the notes. On the contrary, they are useful as imparting character and expression to the music. Of this kind are most stringed instruments, and most pipes furnished with tongues, etc. Sounds in which the harmonics are particularly strong acquire thereby a peculiarly penetrating character; such are those yielded by brass instruments.

CHAPTER III.

TRANSVERSE VIBRATIONS OF STRINGS. STRINGED INSTRUMENTS.

174. **Transverse vibrations of strings.**—We have already seen (153), that when an elastic string, stretched at the ends, is removed from its position of equilibrium, it reverts to it as soon as it is let go, making a series of vibrations which produce a sound. The strings used in music are commonly of catgut or metallic wire. The vibrations which strings experience may be either *transversal* or *longitudinal*, but practically the former are alone important. *Transversal vibrations* may be produced by drawing a bow across the string, as in the case of the violin; or by striking the string, as in the case of the pianoforte; or by pulling them transversely and then letting them go suddenly, as in the case of the guitar and the harp.

175. **Laws of the transverse vibrations of strings.**—The number of transverse vibrations which a string can give in a

certain time, that is, the sound it yields, vary with its length, its diameter, its tension, and with its specific gravity, in the following manner:

The tension being constant, the number of vibrations in a second is inversely as the length; that is, that if a string makes 18 vibrations in a second for instance, it will make 36 if its length is halved, 54 if its length is one-third, and so on. On this property depends the violin, the contre basso, etc., for in these instruments, by pressing the string with a finger, the length is reduced or increased at pleasure, and the number of vibrations, and therewith the note, is regulated.

With strings of the same length and tension *the number of vibrations in a second is inversely as the radius of the string*; that is, the thinner a string, the greater its number of vibrations, and the higher its pitch. In the violin, the treble string, which is the thinnest, makes double the number of vibrations of that which would be made by a string twice its size, that is to say, the diameter of which is twice as great.

The number of vibrations in a second is directly as the square root of the stretching weight or tension; that is, that when the tension of a string is four times as great, the number of vibrations is doubled; when the tension is nine times as great, the number is trebled, and so on. This, then, furnishes a means of altering the character of a note by stretching, as is done in stringed instruments.

Other strings being equal, *the number of vibrations in a second of a string is inversely as the square root of its density.* Hence, the greater the density of the materials of which strings are made, the less easily they vibrate, and the deeper are the sounds they yield.

From the preceding laws it will be seen how easy it is to vary the number of the vibrations of strings and make them yield an extreme variety of sounds, from the deepest to the highest, used in music.

176. **Verification of the laws of the vibrations of strings. Sonometer.**—This may be effected by means of an instrument called the *sonometer*, or *monochord.* It consists of a thin wooden box to strengthen the sound. On this there are two fixed bridges A and B (fig. 144), over which pass the strings AB, CD, which are commonly metallic wires. These are fastened at one end, and stretched at the other by a weight P, which can be increased at will. By means of a third movable bridge D, the length of that

portion of the wire which is to be put in vibration can be altered at pleasure.

If two strings are taken, which are identical in all respects and are

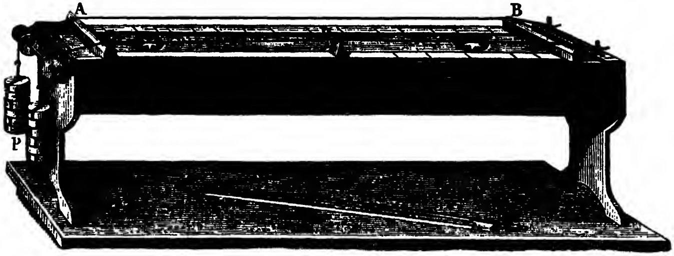

Fig. 144.

stretched by equal weights, they will be found, on being struck, to yield the same sound. If now one of them be divided by the movable bridge D into two equal parts, the sound yielded by CD will be the higher octave of that yielded by the entire string AB, which shows that the number of vibrations is doubled, and thus verifies the law.

To verify the second law, the bridge D is removed. If the string AB is taken so that it has double the size of the other, but both stretched by the same weight, it will be found that the sound which the thinnest string yields is the next higher octave of that yielded by AB; proving thus that the number of vibrations is doubled.

The two strings being of the same diameter, and the same length, if the weight which stretches the one be four times that which stretches the other, the sound yielded by the first is the higher octave of that of the second, which shows that the number of vibrations is doubled; when the weight is nine times as great, the sound is the higher octave of the fifth of the former.

The fourth law is established by using strings of different densities, but of the same dimensions, and stretched to the same extent.

177. **Stringed instruments.**—Stringed musical instruments depend on the production of transverse vibrations. In some, such as the piano, the sounds are *constant*, and each note requires a separate string: in others, such as the violin and guitar, the sounds are *varied* by the fingering, and can be produced by fewer strings.

In the piano the vibrations of the strings are produced by the stroke of the *hammer*, which is moved by a series of bent levers

communicating with the keys. The sound is strengthened by the vibrations of the air in the sounding board on which the strings are stretched. Whenever a key is struck, a *damper* is raised, which falls when the finger is removed from the key and stops the vibrations of the corresponding string. By means of a *pedal* all the dampers can be simultaneously raised, and the vibrations then last for some time.

The harp is a sort of transition from the instruments with constant to those with variable sounds. Its strings correspond to the natural notes of the scale: by means of the pedals the lengths of the vibrating parts can be changed, so as to produce sharps and flats. The sound is strengthened by the sounding box, and by the vibrations of all the strings harmonic with those played.

In the violin and guitar each string can give a great number of sounds, according to the length of the vibrating part, which is determined by the pressure of the fingers of the left hand while the right hand plays the bow, or the strings themselves. In both these instruments the vibrations are communicated to the upper face of the sounding box, by means of the bridge over which the strings pass. These vibrations are communicated from the upper to the lower face of the box, either by the sides, or by an intermediate piece called the *sound post.* The air in the interior is set in vibration by both faces, and the strengthening of the sound is produced by all these simultaneous vibrations. The value of the instrument consists in the perfection with which all possible sounds are intensified, which depends essentially on the quality of the wood, and the relative arrangement of the parts.

Instruments of the class of the violin are very difficult to play, and require a very delicate ear; but in the hands of skilful artists, they produce marvellous effects. They are the very soul of an orchestra, and the most beautiful pieces of music have been composed for them.

CHAPTER IV.

SOUNDING TUBES AND WIND INSTRUMENTS.

178. **Production of sound in pipes.**—Sounding pipes are hollow pipes or tubes in which sounds are produced by making the enclosed column of air vibrate. In the cases hitherto considered the sound

results from the vibrations of solid bodies, and the air only serves as a vehicle for transmitting them. In wind instruments, on the contrary, when the sides of the tube are of adequate thickness, the enclosed column of air is the sonorous body. In fact, the substance of the tubes is without influence on the primary tone: with equal dimensions it is the same whether the tubes are of glass, of wood, or of metal. These different materials simply do no more than give rise to different harmonics, and impart a different timbre to the compound tone produced.

If tubes were simply blown into, there could be no sound; there would merely be a continuous progressive motion of the air. To produce a sound, by some means or other a rapid succession of

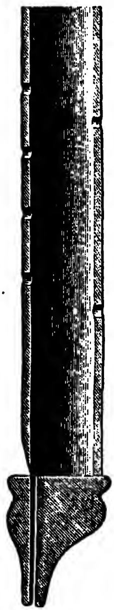

Fig. 145. Fig. 146. Fig. 147. Fig. 148. Fig. 149.

condensations and rarefactions must be produced, which are then transmitted to the whole column of air in the tube. Hence the necessity of having a *mouthpiece*, that is, the end by which air enters,

so shaped that the air enters in an intermittent, and not a continuous manner. From the arrangement made use of to set air in vibration, wind instruments are divided into *mouth* instruments and *reed* instruments.

179. **Mouth instruments**.—In mouth instruments all parts of the mouthpiece are fixed. The pipes are either of wood or metal, rectangular or cylindrical, and are always long as compared with the diameter. Fig. 145 represents a wooden rectangular organ pipe; fig. 146 gives a longitudinal section by which the interval details are seen. The lower part P, by which air enters, is called the *foot*; it emerges through a narrow slit, *and*, on the opposite side, is a transverse aperture called the *mouth*; *a* and *b* are the *lips*, the upper one of which is bevelled.

The current of air arising by the mouth, strikes against the upper lip, is compressed, and by its elasticity reacts upon the current and stops it. This, however, only lasts for an instant, for, as the air escapes at *ab*, the current from the foot continues, and so on for the whole time.

In this way, pulsations are produced, which, transmitted to the air in the pipe, make it vibrate, and a sound is the result. In order that a pure note may be produced, there must be a certain relation between the form of the lips and the magnitude of the mouth; the tube also ought to have a great length in comparison with its diameter. The number of vibrations depends in general on the dimensions of the pipe, and the velocity of the current of air.

The mouthpiece we have described is used in organs. Fig. 147 represents another modification much in use in organ playing, and fig. 148 gives a longitudinal section. The letters indicate the same parts as in fig. 146. Fig. 149 shows the mouthpiece of a flageolet and whistle. In the German flute the mouthpiece consists of a small lateral circular aperture in the pipe. By means of his lips the player causes the current of air to graze against the edge of this aperture.

180. **Reed instruments.**—In reed instruments the air is set in vibration by means of elastic tongues or plates, which are called reeds, and which are divided into free reeds and beating reeds.

Beating reed. This consists of a piece of wood or metal, *a* (fig. 151), which is grooved like a spoon. It is fixed to a kind of stopper, K, perforated by a hole, which connects the cavity with a long pipe, T. The groove is covered by a brass plate, *l*, which is called the *tongue*. In its ordinary position this is slightly away from the edges of the groove, but being very flexible, readily

approaches, and closes it. Lastly, a curved wire, *br*, presses against the tongue, and can be moved up and down.

The vibrating part of the tongue can thereby be shortened or lengthened at will, and the number of vibrations thus regulated. By means of this wire, reed pipes are tuned.

The reed is fitted to the top of a rectangular pipe KN, called the *wind channel.* This is closed everywhere except at the bottom,

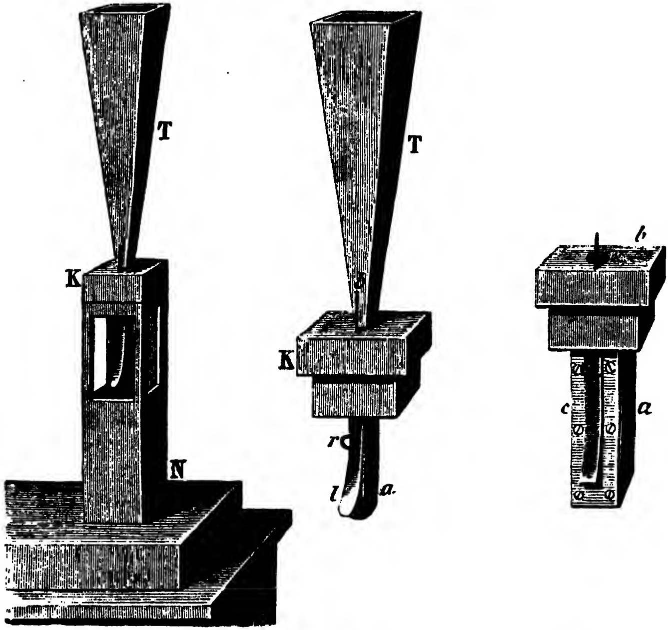

Fig. 150. Fig. 151. Fig. 152.

where it can be fitted on a bellows. In models of reed pipes used in illustrating lectures, the sides of the upper part of the tube are made of glass, so as to show the construction of the reed. This arrangement is represented in fig. 150.

When air arrives in the wind channel, it first passes between the tongue and the groove, and escapes by the pipe T; but as the velocity increases, the tongue strikes against the edge of the groove, and closing it completely, the current is stopped. But, in virtue of its elasticity, the tongue reverts to its original position, and thus by a

series of alternate openings and closings, the same series of pulsations are produced as in mouth instruments; hence is formed a sound which is higher the more rapid the current of air.

Free reed. Grenié invented in 1810 a kind of reed called a *free reed*, because the tongue, instead of striking against the edges of the groove, like the reed described above, grazes them so as to oscillate backwards and forwards. The groove consists, in this case, of a small wooden box, *ac*, the front of which is of brass plate. In the middle of this is a longitudinal slit, in which is applied the tongue, which can oscillate freely backwards and forwards so as to allow air to pass, which it closes each time it grazes the edges of the slit. In this case also a wire, *r*, regulates the length of the vibrating part of the tongue.

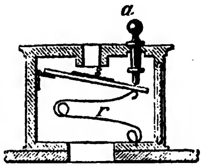

Fig. 154.

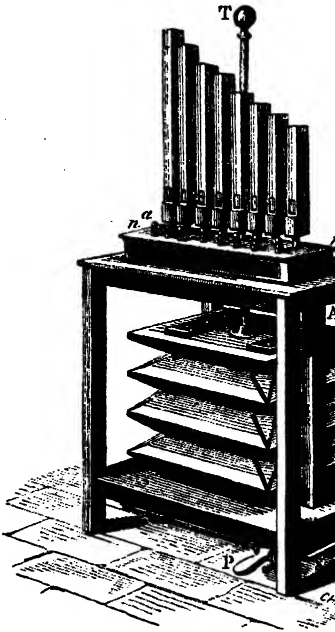

Fig. 153.

181. **Bellows.**—In acoustics a *bellows* is an apparatus by which wind instruments, such as the syren and organ pipes, are worked.

Between the four legs of a table there is a pair of bellows, S (fig. 153), which is worked by means of a pedal, P. D is a reservoir of flexible leather, in which is stored the air forced in by the bellows. If this reservoir is pressed by means of weights on a rod, T, moved by the hand, the air is driven through a pipe, A, into a *wind* chest, *mn*, fixed on the table. In this chest there are small holes closed by leather valves, *s* (fig. 154). These can be opened by pressing on keys, *a*, in front of the box. Below the valve is a spring, *r*, which raises the valve when the key is not depressed. The syren or sounding pipe is placed in one of these holes.

182. **Nodes and loops.**—Experiment shows, that when a pipe is sounded, the column of air is subdivided into equal parts, vibrating in unison, and separated by surfaces where the velocity of air is null. These fixed parts are called *nodes*; and the parts between the nodes where the column of air is in a state of vibration is called a *loop*, or a *ventral* segment.

It will be seen afterwards, that one and the same pipe may be made to yield several sounds, and that the nodes and ventral segments are then displaced. When a pipe closed at one end, *a stopped pipe*, is made to yield its fundamental sound, that is, the deepest one, the bottom is always a node, and the mouthpieces a ventral segment. An open pipe when sounded has a ventral segment at each end; and if it yields the fundamental sound, there is a single node in the middle.

When an aperture is opened in the side of a sounding pipe, the sound does not change if the aperture corresponds to a loop; but if it corresponds to a node, the sound is altered, for this node then becomes a loop. This property is used in wind instruments like the flute, the clarionet, along which holes are made which can be closed by the fingers, or by the aid of keys.

The formation of nodes and loops is far from being restricted to sounding tubes. On strings, plates and membranes, when they vibrate, exhibit parts which are fixed, and parts which are very mobile, that is to say, nodes and loops.

182*a*. **Laws of the vibration of air in pipes.**—The vibrations of air in pipes present two cases according as they are *open* or *stopped.*

Laws of stopped pipes. When having placed a stopped pipe on the bellows, air is slowly passed, the deepest note, the fundamental sound, is produced. If, then, we denote by 1 the corresponding number of vibrations, when the current of air is forced, we suddenly get the sound corresponding to 3; and if the wind be still more

forced, we have successively the sounds 5, 7, etc.; that is to say, sounds which by their pitch correspond to vibrations 3, 5, 7, etc. times as numerous as those of the fundamental sound. Hence *closed pipes, when the air is forced, give successively sounds represented by the series of odd numbers.*

The sounds 3, 5, 7, etc., are called the *harmonics* of the fundamental note 1.

2. *With pipes of different lengths, the number of vibrations corresponding to the fundamental note are inversely as the lengths;* that is to say, that a pipe, which is half as long as another, will yield a sound which is the octave of that yielded by this pipe.

Laws of open pipes. The fundamental note being still represented by unity, the harmonics obtained by forcing the wind are successively represented by 2, 3, 4, 5, 6, etc., that is, *by the natural series of numbers.*

The fundamental note of an open pipe is always an octave higher than the fundamental note of a closed pipe of the same length.

These laws are known as Bernouilli's laws from the name of their discoverer, Daniel Bernouilli.

183. **Wind instruments.**—Wind instruments are straight or curved tubes, which are sounded by means of a current of air forced into them. They have all an aperture by which air is forced into them, and, according to the form of this aperture, they are divided into mouth instruments and reed instruments; in some, such as the organ, the notes are *fixed*, and require a separate pipe for each note; in others the notes are *variable*, and are produced by only one tube: the flute, horn, etc., are of this class.

The Pandæan pipe, the flageolet, and the German flute are mouth instruments. The principal reed instruments are the clarionet, the oboe, the cornopean, and the bassoon.

The *Pandæan pipe* consists of tubes of different sizes corresponding to the different notes of the gamut.

In the *organ* the pipes are of various kinds, namely, mouth pipes, open and stopped, and reed pipes with apertures of various shapes. The air is furnished by means of bellows, from which it passes into the wind chest, and thence into any pipe which is desired; this is effected by means of valves which are opened by depressing keys like those of the piano. In the larger and richer organs there are several rows of key-boards arranged at different heights.

In the *flute*, the mouthpiece consists of a simple lateral circular aperture; the current of air is directed by means of the lips, so

that it grazes the edge of the aperture. The holes at different distances are closed either by the fingers or by keys; when one of the holes is opened, a loop is produced in the corresponding layer of air, which modifies the distribution of nodes and loops in the interior, and thus alters the note. The whistling of a key is similarly produced.

Mouth instruments. In the trumpet, the horn, the trombone, cornet-à-piston, and ophicleide, the lips form the reed, and vibrate in the mouthpiece (fig. 155), which terminates in a smaller tube by which it can be affixed to the instrument. In the *horn*, different notes are produced by altering the distance of the lips. In the *trombone*, one part of the tube slides within the other, and the performer can alter at will the length of the tube, and thus produce higher or lower notes. In the *cornet-à-piston*, the tube forms several convolutions; pistons placed at different distances can, when played, cut off communications with other parts of the tube, and thus alter the length of the vibrating column of air.

Fig. 155.

The *tuning-fork*, the *triangle*, and *musical boxes* are examples of the transverse vibrations of rods. In musical boxes small plates of steel of different dimensions are fixed on a rod, like the teeth of a comb. A cylinder, whose axis is parallel to this rod, and whose surface is studded with steel teeth, arranged in a certain order, is placed near the plates. By means of a clockwork motion the cylinder rotates, and the teeth striking the steel plates set them in vibration, producing a tune, which depends on the arrangement of the teeth on the cylinder.

BOOK V.

HEAT.

CHAPTER I.

GENERAL EFFECTS OF HEAT. THERMOMETERS.

184. **Heat. Hypothesis as to its nature.**—The sensations of heat and cold are familiar to all of us. In ordinary language the term *heat* is not only used to express a particular sensation, but also to describe that particular state or condition of matter which produces this sensation. Besides this effect, heat acts variously upon bodies; it melts ice, boils water, makes metals red-hot, and so forth.

Two theories as to the cause of heat are current at the present time; these are the *theory of emission*, and the theory of *undulation.*

On the first theory, heat is caused by a subtle imponderable fluid, which surrounds the molecules of bodies, and which can pass from one body to another. These *heat atmospheres*, which thus surround the molecules, exert a repelling influence on each other, in consequence of which heat acts in opposition to the force of cohesion. The entrance of this substance into our bodies produces the sensation of warmth, its egress the sensation of cold.

On the second hypothesis the heat of a body is caused by an oscillating or vibratory motion of its material particles, and the hottest bodies are those in which the vibrations have the greatest velocity and the greatest amplitude. Hence, on this view, heat is not a *substance*, but a *condition of matter*, and a condition which can be transferred from one body to another. It is also assumed that there is an imponderable elastic ether, which pervades all bodies and infinite space, and is capable of transmitting a vibratory motion with great velocity. A rapid vibratory motion of this ether produces heat, just as sound is produced by a vibratory motion of

atmospheric air, and the transference of heat from one body to another is effected by the intervention of this ether.

This hypothesis is now admitted by the most distinguished physicists; it affords a better explanation of the phenomena of heat than any other theory, and it reveals an intimate connection between heat and light. In accordance with it, heat is a *form of motion*; and it will hereafter be shown that heat may be converted into motion, and, conversely, motion may be converted into heat.

Although the undulatory theory of heat is the correct one, the one, that is, which best explains and accounts for the greatest number of facts, yet it may be sometimes convenient to use language which is based on the older hypothesis. Thus, in speaking, of a body becoming heated or cooled, we say that it gains or loses heat; in reality, the motion of the particles is increased or diminished.

In what follows, however, the phenomena of heat wlll be considered, as far as possible, independently of either hypothesis.

185. **General effects of heat.**—The general action of heat upon bodies is to develope a repulsive force between their molecules which is continually struggling with molecular attraction. Under its influence, therefore, bodies tend to *expand*—that is, to assume a greater volume.

All bodies expand by the action of heat. As a general rule gases are the most expansible, then liquids, and, lastly, solids. The expansion of bodies by heat is thus a new general property to be added to those already studied.

The action of heat upon bodies is not merely to expand them; when accumulated in sufficient quantity, bodies first lose their solidity and become somewhat softer; then, as the heat still increases, the force of repulsion balances molecular attraction, and then bodies liquefy. Wax, resin, sulphur thus pass readily from the solid to the liquid state; heat thus produces in solids a change of state of aggregation. But in liquids it produces a similar change. When bodies are heated they first expand; heated still more their molecular attraction is again overcome by the force of repulsion, and bodies are then changed into aëriform fluids called vapours.

If, instead of becoming accumulated in bodies heat is given out, that is, if bodies are cooled instead of being heated, the opposite phenomena are produced: the molecules come nearer each other,

the volume of the pores diminishes, and hence that of the body, which is expressed by saying that the body *contracts.* By cooling, vapours losing their elastic force revert to the liquid state; and liquids themselves, by the same process, gradually revert to the solid state. Thus water changes into ice, and mercury becomes as hard as lead.

Thus, according as heat accumulates in, or is dissipated by, bodies, two physical effects may be produced: 1, changes in volume, consisting in expansions and contractions. 2. Changes of condition, that is, the change of solids into liquids, of liquids into vapours, and conversely. We shall first discuss the expansion of bodies, and afterwards their changes of state.

186. **Expansion.**—All bodies are expanded by heat, but to very different extents. Gases are most expansible, then liquids, and after them solids.

In solids which have definite figures, we can either consider the expansion in one dimension, or the *linear* expansion; in two dimensions, the *superficial* expansion, or in three dimensions, the *cubical* expansion or the expansion of volume, although one of these never takes place without the other. As liquids and gases have no definite figures, the expansions of volume have in them alone to be considered.

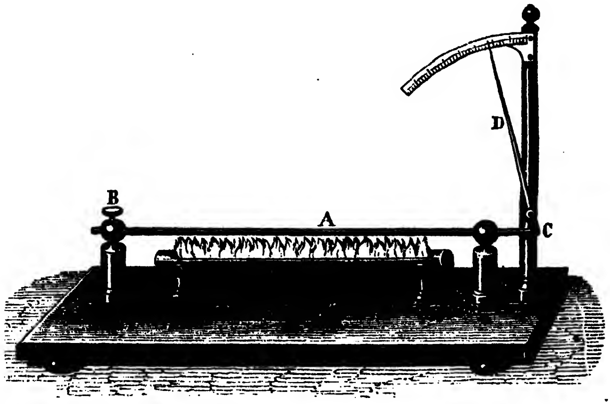

Fig. 156.

To show the linear expansion of solids, the apparatus represented in fig. 156 may be used. A metallic rod, A, is fixed at one end by

a screw, B, while the other end presses against the short arm, C, of an index, D, which moves on a scale. Below the rod, A, there is a sort of cylindrical lamp in which alcohol is burned. The needle, D, is at first at the zero point, but, as the rod becomes heated, the needle moves along the scale, which shows that the short arm, C, of the lever is slightly displaced, pushed by the rod, A, as it expands.

It will be observed that if rods of different metals are used, the index will be moved to different extents, showing that their expansibility differs. Thus it will be found that brass is more expansible than iron, or steel.

The cubical expansion of solids is shown by a *Gravesande's* ring. It consists of a brass ball, *a* (fig. 157), which at the ordinary temperature passes freely through a ring, *m*, almost of the same diameter. But when the ball has been heated, it expands and no longer passes through the ring. It does so, however, on reverting to its original temperature. The expansibility of liquids and gases, which is far greater than that of solids, is easily shown. For a liquid a glass tube with a bulb at one end may be used (fig. 158), which is filled with some liquid, coloured alcohol or mercury, for instance. When the bulb is gently heated,

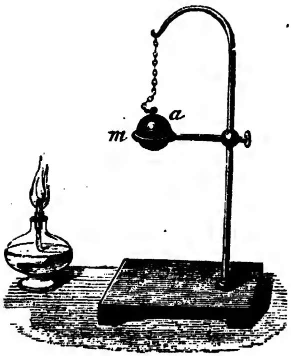

Fig. 157.

Fig. 158.

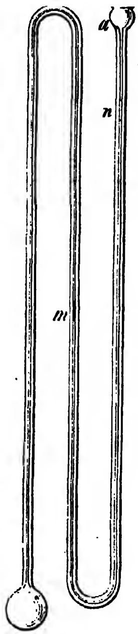

Fig. 159.

by placing it in tepid water, for example, the column of liquid is seen to rise considerably in the tube thus, from *a* to *b*.

The experiment may be made in a similar manner with gases; yet as they are far more expansible than liquids, a long tube bent twice may be fused to the bulb tube, as represented in fig. 159 An index of mercury, *m*, is introduced in the tube, which is effected by gently heating the bulb so as to expel some of the air; a drop of mercury being then placed in the funnel, *a*, on cooling the air in the bulb and the tube contracts, and the pressure of the atmosphere forces the droplet to *m* for instance. The apparatus being thus arranged, if the bulb is held in the hand for a few moments, the enclosed air expands sufficiently to force the index from *m* to *n*, an expansion which is far greater than in the case of liquid.

It will thus be seen that the general effect of heat upon bodies is to expand them. Yet this only applies to bodies which, like the metals, glass, etc. do not absorb moisture. Bodies which absorb moisture, such as wood, paper, clay, undergo a contraction when heated, owing to the increase of temperature expelling moisture from their pores. Thus a moist sheet of paper placed before the fire coils up on the heated side. Coopers, too, to curve the staves of barrels, heat them on one side, by lighting a fire in the inside of the barrel when the staves are placed in juxtaposition. The part turned towards the fire in drying contracts, and is curved on the side exposed to the action of heat.

MEASUREMENT OF TEMPERATURES. THERMOMETRY.

187. **Temperature.**—The *temperature* or hotness of a body may be defined as being the greater or less extent to which it tends to impart sensible heat to other bodies. The temperature of any particular body is varied, by adding to it or withdrawing from it a certain amount of sensible heat. The temperature of a body must not be confounded with the *quantity* of heat it possesses; a body may have a high temperature and yet have a very small quantity of heat, and conversely a low temperature may yet possess a large amount of heat. If a cup of water be taken from a bucketful, both will indicate the same temperature, yet the quantities of heat they possess will be different. This subject of the quantity of heat will be afterwards more fully explained in the chapter on SPECIFIC HEAT.

188. **Thermometers.**—*Thermometers* are instruments for measur-

ing temperatures. Owing to the imperfections of our senses we are unable to measure temperatures by the sensations of heat or cold which they produce in us, and for this purpose recourse must be had to the physical effects of heat upon bodies. The most accurate and the most convenient are the expansive effects. Solids, having but little expansibility, can only be used to examine large intervals of temperature; gases, on the other hand, are very expansible, and only serve to measure small alterations of temperature. For these reasons, liquids are best suited for the construction of thermometers. Mercury and alcohol are the only ones used—the former because its expansion is regular, and it only boils at a very high temperature, and the latter because it does not solidify at the greatest known cold.

Fig. 160.

Fig. 161.

The mercurial thermometer is the most extensively used. It consists of a capillary glass tube, at the end of which is blown the *bulb*, a cylindrical or spherical reservoir (fig. 160). Both the bulb and a part of the stem are filled with mercury, and the expansion is measured by a scale graduated either on the stem itself, or on a frame to which it is attached.

The filling of the tube with mercury is effected by fusing to the tube a small funnel as shown in fig. 160. In this is placed a small quantity of mercury, and the bulb is then gently heated by a spirit lamp. The expanded air partially escapes by the funnel, and on cooling, the air which remains contracts, and a portion of the mercury passes into the bulb. The bulb is then again warmed, and allowed to cool, a fresh quantity of mercury enters, and so on, until the bulb and part of the tube are full of mercury. The mercury is then heated to boiling; the mercurial vapours in escaping carry with them the air and moisture which remain in the tube. The tube being full of the expanded mercury and of mercurial vapour, is hermetically sealed

at one end. When the thermometer is cold the mercury ought to fill the bulb and a portion of the stem.

189. **Graduation of the thermometer.**—The thermometer being filled, as has just been described, whenever the temperature rises or sinks, the mercury rises or sinks in the stem, and these variations furnish a means of measuring temperatures. For this purpose a graduated scale must be constructed along the stem. In graduating the scale two points must be fixed, which represent identical temperatures and can always be easily produced.

Experiment has shown that ice always melts at the same point whatever be the degree of heat, and that distilled water under the same pressure, and in a vessel of the same kind, always boils at the same temperature. Consequently, for the first fixed point, or zero, the temperature of melting ice has been taken; and, for a second fixed point, the temperature of boiling water in a metallic vessel under the normal atmospheric pressure of 30 inches.

This interval of temperature, that is, the range from zero to the boiling point, is taken as the unit for comparing temperatures; just as a certain length, a foot or a yard for instance, is used as a basis for comparing lengths.

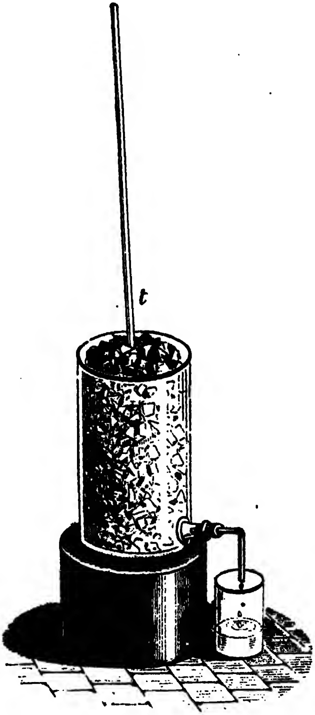

Fig. 162.

To obtain zero, snow or pounded ice is placed in a vessel, in the bottom of which is an aperture by which water escapes (fig. 162). The bulb and a part of the stem of the thermometer are immersed in this for about a quarter of an hour; the mercury sinks, and the level at which it finally rests is marked by tying a piece of thread round the pipe.

The second fixed point is determined by means of the apparatus

represented in fig. 163. It consists of a tin-plate vessel containing distilled water, in the lid of which is a long tube. The thermo-

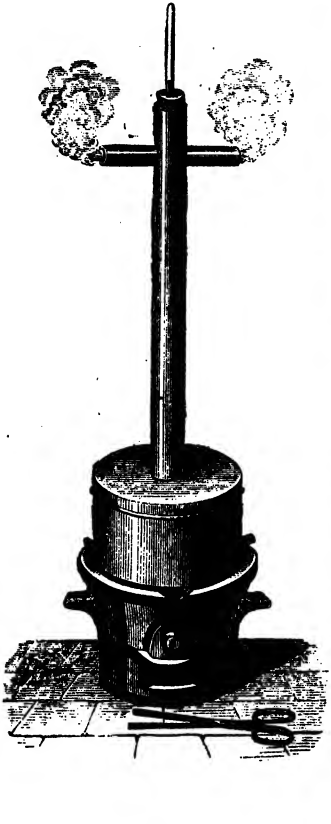

Fig. 163.

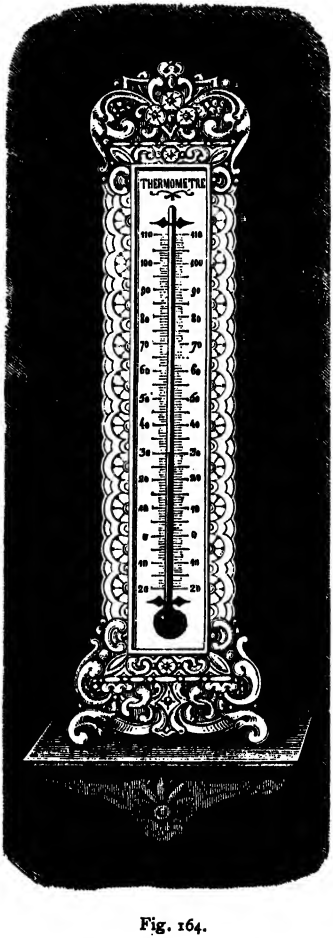

Fig. 164.

meter is placed in this by means of a cork, and the water heated to boiling. The thermometer is thus surrounded by steam, which,

liberated from the liquid, escapes by the lateral apertures. This steam is at the same temperature as the water from which it is liberated, and, when the mercury is stationary, a second mark is made upon the stem.

190. **Construction of the scale.**—Just as the foot-rule which is adopted as the unit of comparison for length is divided into a number of equal divisions called inches, for the purpose of having a smaller unit of comparison, so likewise the unit of comparison of temperatures, the range from zero to the boiling point, must be divided into a number of parts of equal capacity called *degrees.* There are three modes in which this is done. On the Continent, and more especially in France, this space is divided into 100 parts, and this division is called the *Centigrade* or *Celsius* scale; the latter being the name of the inventor. The Centigrade thermometer is almost exclusively adopted in foreign scientific works, and as its use is gradually extending in this country, it has been and will be adopted in this book.

The degrees are designated by a small cipher placed a little above on the right of the number which marks the temperature, and to indicate temperature below zero the minus sign is placed before them. Thus -15° signifies 15 degrees below zero.

In accurate thermometers the scale is marked on the stem itself (fig. 165). It cannot be displaced, and its length remains fixed, as glass has very little inexpansibility. This is effected by covering the stem with a thin layer of wax, and then marking the divisions of the scale, as well as the corresponding numbers with a steel point. The thermometer is then exposed for about ten minutes to the vapours of a substance called *hydrofluoric acid*, which attacks the glass where the wax has been removed. The rest of the wax is then removed, and the stem is found to be permanently etched.

Fig. 165.

Scales are also constructed on plates of ivory, wood, or metal, against which the stem is placed. Fig. 164 represents a mercury thermometer mounted on ivory; its scale extends from 20 degrees below zero to 110 degrees above.

Besides the *Centigrade* scale two others are frequently used—*Fahrenheit's scale* and *Réaumur's scale.*

In Réaumur's scale the fixed points are the same as on the Centigrade scale, but the distance between them is divided into 80 degrees instead of into 100. That is to say, 80 degrees Réaumur are equal to 100 degrees Centigrade ; one degree Réaumur is equal to $\frac{100}{80}$ or $\frac{5}{4}$ of a degree Centigrade, and one degree Centigrade equals $\frac{88}{100}$ or $\frac{4}{5}$ degree Réaumur. Consequently to convert any number of Réaumur degrees into Centigrade degrees (20 for example), it is merely necessary to multiply them by $\frac{5}{4}$ (which gives 25). Similarly, Centigrade degrees are converted into Réaumur's by multiplying them by $\frac{4}{5}$.

The thermometric scale invented by Fahrenheit in 1714 is still much used in England, and also in Holland and North America. The higher fixed point is like that of the other scales, the temperature of boiling water, but the null-point or zero is the temperature obtained by mixing equal weights of sal-ammoniac and snow, and the interval between the two points is divided into 212 degrees. The zero was selected because the temperature was the lowest then known, and was thought to represent absolute cold. When Fahrenheit's thermometer is placed in melting ice it stands at 32 degrees, and, therefore, 100 degrees on the Centigrade scale are equal to 180 degrees on the Fahrenheit scale, and thus 1 degree Centigrade is equal to $\frac{9}{5}$ degree Fahrenheit, and inversely 1 degree Fahrenheit is equal to $\frac{5}{9}$ of a degree Centigrade.

If it be required to convert a certain number of Fahrenheit degrees (95 for example) into Centigrade degrees, the number 32 must first be subtracted, in order that the degrees may count from the same part of the scale. The remainder in the example is thus 63, and as 1 degree Fahrenheit is equal to $\frac{5}{9}$ of a degree Centigrade, 63 degrees are equal to $63 \times \frac{5}{9}$ or 35 degrees Centigrade.

If F be the given temperature in Fahrenheit's degrees and C the corresponding temperature in Centigrade degrees, the former may be converted into the latter by means of the formula

$$(F-32)\,\tfrac{5}{9}=C,$$

and conversely, Centigrade degrees may be converted into Fahrenheit by means of the formula

$$\tfrac{9}{5}C+32=F.$$

These formulæ are applicable to all temperatures of the two scales, provided the signs are taken into account. Thus, to convert the

temperature of 5 degrees Fahrenheit into Centigrade degrees we have

$$(5-32)\,\tfrac{5}{9} = \frac{-27\times 5}{9} = -15\text{C.}$$

In like manner we have for converting Réaumur's into Fahrenheit's degrees the formula

$$\tfrac{9}{4}\text{R} + 32 = \text{F.},$$

and conversely, for changing Fahrenheit's into Réaumur's degrees, the formula

$$(\text{F}-32)\,\tfrac{4}{9} = \text{R.}$$

191. **Alcohol thermometer.**—The *alcohol thermometer* differs from the mercurial thermometer in being filled with coloured alcohol. But as the expansion of liquids is less regular in proportion as they are near the boiling point, alcohol, which boils at 78° C., expands very irregularly. Hence, alcohol thermometers are usually graduated by placing them in baths at different temperatures together with a standard mercurial thermometer.

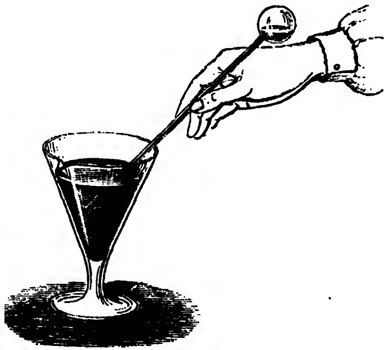
Fig. 166.

It is filled by gently heating the bulb, so as to repel a certain quantity of air, and then inverting it and plunging the open end of it into alcohol (fig. 166). The interior air contracts on cooling, and the atmospheric pressure raises the alcohol in the tube and in the bulb. It does not at first fill it completely, for some air remains; but the alcohol is then boiled, and its vapours expel all the air; the tube is then again inverted and placed in alcohol, and now the instrument becomes quite filled. The further construction resembles that of a mercurial thermometer.

192. **Limits to the employment of mercurial thermometers.**—Of all thermometers in which liquids are used, the one with mercury is the most useful, because this liquid expands most regularly, and is easily obtained pure, and because its expansion between $-36°$ and 100° is *regular*, that is, proportional to the degree of heat. It

also has the advantage of having a very low specific heat. But for temperatures below $-36°$ C. the alcohol thermometer must be used, for mercury solidifies at $-40°$ C. to a mass like lead. Above 100 degrees the coefficient of expansion increases and the indications of the mercurial thermometers are only approximate, the error amounting sometimes to several degrees. Mercurial thermometers also cannot be used for temperatures above 350°, for this is the boiling point of mercury.

Observations by means of the thermometer. In taking the temperature of a room, the thermometer is usually suspended against the wall. This may, however, give rise to an error of several degrees; for if the wall communicates with the outside, and especially if it has a northern aspect, it will, generally speaking, be colder than the air in the room, and will communicate to the thermometer too low a temperature. On the other hand it may happen that the wall becomes too much heated by the sun's rays, or by chimney flues, and then the thermometer will be too high. The only way to obtain with accuracy the temperature of the air in a room is to suspend the thermometer by a string in the centre, at a distance from any object which might raise or lower its temperature. The same remark applies to the determination of the temperature of the atmosphere; the thermometer must be suspended in the open air, in the shade, and not against a wall.

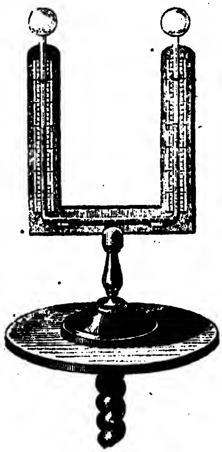

Fig. 167.

193. **Leslie's differential thermometer.**—Sir John Leslie constructed a thermometer for showing the difference of temperature of two neighbouring places, from which it has received the name *differential thermometer.* It consists of two glass bulbs containing air, and joined by a bent glass tube of small diameter fixed on a frame (fig. 167). Before the apparatus is sealed, a coloured liquid is introduced in sufficient quantity to fill the horizontal part of the tube, and about half the vertical legs. It is important to use a liquid which does not give off vapours at ordinary temperatures, and dilute sulphuric acid coloured with litmus is generally preferred. The apparatus being closed the air is passed

from one bulb into the other by heating them unequally until the level of the liquid is the same in both branches. A zero is marked at each end of the liquid column. To graduate the apparatus, one of the bulbs is raised to a temperature 10° higher than the other. The air of the first is expanded and causes the column of liquid, *ba*, to rise in the other leg. When the column is stationary the number 10 is marked on each side at the level of the liquid, the distance between zero and 10 being divided into 10 equal parts, both above and below zero, on each leg.

194. **Rutherford's maximum and minimum thermometers.**—It is necessary, in meteorological observations, to know the highest temperature of the day, and the lowest temperature of the night. Ordinary thermometers could only give these indications by a continuous observation, which would be impracticable. Several instruments have accordingly been invented for this purpose, the simplest of which is Rutherford's. On a rectangular piece of plate glass (fig. 168) two thermometers are fixed, whose stems are bent hori-

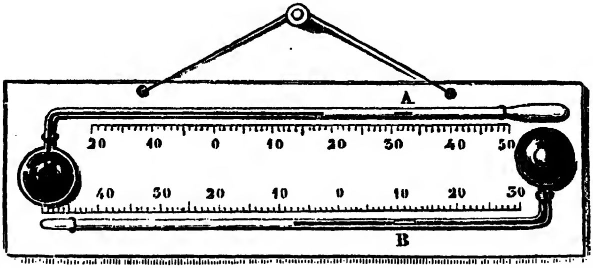

Fig. 168.

zontally. The one, A, is a mercurial, and the other, B, an alcohol thermometer. In A there is a small piece of iron wire, A, moving freely in the tube, which serves as an index. The thermometer being placed horizontally, when the temperature rises the mercury pushes the index before it. But as soon as the mercury contracts, the index remains in that part of the tube to which it has been moved, for there is no adhesion between the iron and the mercury. In this way the index registers the highest temperature which has been obtained; in the figure this is 31°. In the minimum thermometer there is a small hollow glass tube which serves as index. When it is at the end of the column of liquid, and the temperature falls, the column contracts and carries the index with it, in consequence

of adhesion, until it has reached the greatest contraction. When the temperature rises, the alcohol expands, and passing between the sides of the tube and the index does not displace B. The position of the index gives therefore the lowest temperature which has been reached : in the figure this was 9½ degrees below zero.

195. **Pyrometers.**—The name *pyrometers* is given to instruments for measuring temperatures so high that mercurial thermometers could not be used. The older contrivances for this purpose, Wedgwood's, Daniell's (which in principle resembled the apparatus in fig. 156), Brongniart's, etc., are gone entirely out of use. None of them gives an exact measure of temperature.

CHAPTER II.

RADIATION OF HEAT.

196. **Radiant heat.**—If we stand in front of a fire, or exposed to the sun's heat, we experience a sensation of warmth which is not due to the temperature of the air, for if a screen be interposed the sensation immediately disappears, which would not be the case if the surrounding air had a high temperature. Hence bodies can send out rays which excite heat, and which penetrate through the air without heating it, as rays of light through transparent bodies. Heat thus propagated is said to be *radiated*; and we shall use the terms *ray of heat*, or *thermal*, or *calorific ray*, in a similar sense to that in which we use the term *ray of light*, or *luminous ray*.

We shall find that the property of radiating heat is not confined to incandescent substances, such as a fire, or a lamp, or a red-hot ball, but that bodies of all temperatures radiate heat. Thus a bottle full of hot water and a bottle full of cold water both emit heat; the first emits more as compared with the second, the greater the difference of temperature between the two.

197. **Laws of radiation.**—The radiation of heat is governed by three laws.

I. *Radiation takes place in all directions round a body.* If a thermometer be placed in different positions round a heated body, it indicates everywhere a rise in temperature; at equal distances from the source of heat it indicates the same rise of temperature.

II. *Heat is propagated in a right line.* For, if a screen be placed

in the right line which joins the source of heat and the thermometer, so as to stop the rays, the latter is not affected.

But in passing obliquely from one medium into another, as from air into a glass, calorific like luminous rays become deviated, an effect known as *refraction.* The laws of this phenomenon are the same for heat as for light, and they will be more fully discussed under the latter subject.

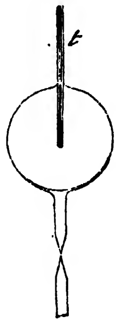

Fig. 169.

III. *Radiant heat is propagated in vacuo as well as in air.* This is demonstrated by the following experiment.

In the bottom of a glass flask a thermometer is fixed in such a manner that its bulb occupies the centre of the flask (fig. 169). The neck of the flask is then carefully narrowed by means of the blowpipe, and then the apparatus having been suitably attached to an air-pump a vacuum is produced in the interior. This having been done, the tube is sealed at the narrow part. On immersing this apparatus in hot water, or on bringing near it some hot charcoal, the thermometer is at once seen to rise. This could only be due to radiation through the vacuum in the interior, for glass is so bad a conductor, that the heat could not travel with this rapidity through the sides of the flask, and the stem of the thermometer.

198. **Causes which modify the intensity of radiant heat.**— The *intensity of radiant heat* transmitted to us by heated bodies depends on the temperature of the source of heat, and on its distance. The corresponding laws may be thus stated :

I. *The intensity of radiant heat is proportional to the temperature of the source.*

II. *The intensity of radiant heat is inversely as the square of the distance.*

The first law is demonstrated by placing a metallic box containing water at 10°, 20°, or 30°, successively, at equal distances from the bulb of a differential thermometer. The temperatures indicated by the latter are then found to be in the same ratio as those of the box : for instance, if the temperature of that corresponding to the box at 10° be 2°, those of the others will be 4° and 6° respectively.

The second law is demonstrated experimentally by placing the differential thermometer at a certain distance from the source of heat, a yard for instance, and then removing it to double the distance. In the latter case, the amount of heat received is not

one-half but one-quarter. If the distance be three yards the quantity of heat is one-ninth, and so forth.

199. **Interchange of heat among all bodies.**—Owing to the radiation which is continually taking place in all directions round a body, there is a continual interchange of heat. If the bodies are all at the same temperature, each one sends to the surrounding ones a quantity equal to that which it receives, and their temperatures remain stationary. But if their temperatures are unequal, as the hot bodies emit more heat than they receive, they therefore sink in temperature; while, as the bodies of lower temperatures receive more heat than they emit, their temperature rises; thus the temperatures are all ultimately equal. The radiation does not stop; it goes on, but without loss or gain from each body, and this condition is accordingly known as the *mobile equilibrium of temperature.*

From what has been said it will be understood, that bodies, placed in our rooms, all tend to assume a uniform temperature; generally speaking this is not the case, for many causes concur in cooling one set, and in heating the others. Thus bodies, placed near a wall, cooled by the exterior atmosphere, find a cause for cooling. Those, on the contrary, which are at the top, tend to acquire a higher temperature; for, as the air is always tending to rise as being less dense, the layers nearest the ceiling are always hotter than the lower ones.

From this continual interchange of heat, there is necessarily a limit to the cooling of bodies, for they always tend to resume, on the one hand, what they lose on the other. To have an indefinite cooling, a body should be suspended in space, not receiving heat from any body. As it then loses heat without acquiring any, there is no telling to what extent its temperature would sink.

CHAPTER III.

REFLECTION OF HEAT. REFLECTING, ABSORBING, AND EMISSIVE POWERS.

200. **Law of the reflection of heat.**—When the heat rays emitted by a source of heat fall upon the surface of a body, they are divided generally into two parts; one, which passes into the mass of a body and raises the temperature; the other, which darts

off from the surface like an elastic ball striking against a hard body; this is expressed by saying that these rays are *reflected.* Thus let A be a source of heat, a cubical box filled with hot water (fig. 170), and near it a screen which does not allow heat to pass, but near the bottom of which is an aperture. If behind this screen a polished surface be placed on which the rays emitted by the cube impinge, and beyond this again a differential thermometer, the latter indicates an increase of temperature when one of its bulbs is so placed that it receives the rays reflected by the polished body. In this experiment, rays like AB which fall on the reflecting surface are called

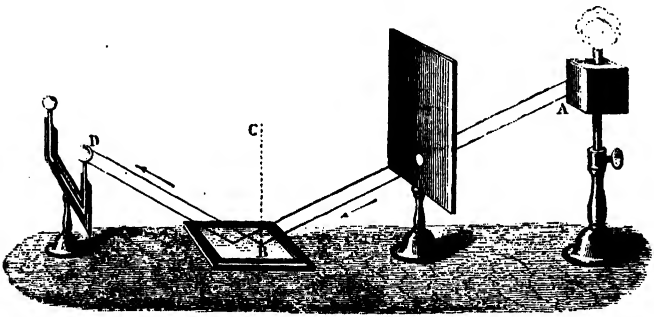

Fig. 170.

incident rays, from a Latin word which signifies to fall; and the *angle of incidence* is not the angle which they make with the reflecting surface, but the angle, ABC, which they make with a right line, BC, perpendicular to this surface. In like manner the angle, CBD, which the reflected rays make with the same straight line, is called the *angle of reflection.*

The reflection of heat is always subject to the law, that *the angle of reflection is equal to the angle of incidence.* We shall subsequently see that the reflection of light is governed by the same law.

201. **Reflection of heat from concave mirrors.**—The effects of the reflection of heat may be very powerful when it takes place from the surface of *concave mirrors*, which are spherical surfaces of glass or of metal. These mirrors may be regarded as being made up of an infinite number of extremely small planes inclined towards each other in such a manner as to determine the curvature. From the symmetrical grouping of these small facets, it follows that when a group of rays fall upon a concave mirror, these rays, in obedience

to the laws of reflection coincide in a single point, to which the name *focus* is applied, to express the great quantity of heat which is concentrated there.

In treating of light we shall discuss in detail the properties of the focus in concave mirrors; for the present it will be sufficient to describe experiments which demonstrate the great intensity which radiant heat may acquire when concentrated in these points. Fig. 171 represents an experiment which is frequently made in physical lectures. Two reflectors, A and B (fig. 171), are arranged at a distance of 4 to 5 yards, and so that their axes coincide. In the focus of one of them, A, is placed a small basket, *n*, containing a red-hot

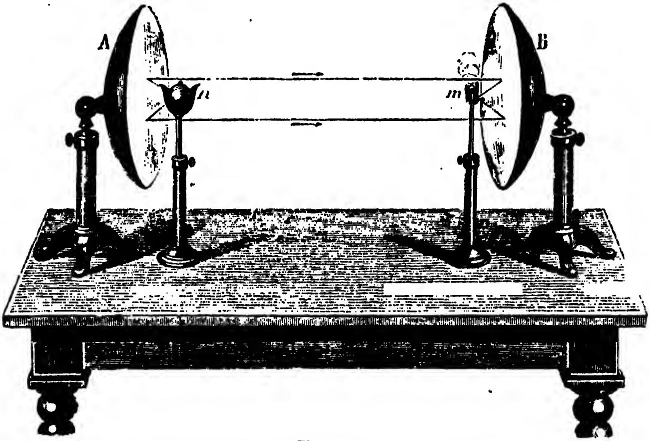

Fig. 171.

iron ball. In the focus of the other, B, is placed an imflammable body, such as gun-cotton or phosphorus. The rays emitted from the focus, *n*, are first reflected from the mirror, A, in a direction parallel to the axis; and impinging on the other mirror, B, are reflected so that they coincide in the focus *m*. That this is so, is proved by the fact that the inflammable substance placed in this point takes fire, which is not the case if it is above or below it.

The same effect may be produced by the sun's rays. For this purpose a concave reflector is so placed that the sun'srays strike directly against it (fig. 172), and if then a combustible substance, such as paper, wood, cork, etc., be held by means of a pincette in the focus, these bodies are seen to take fire. The effect produced depends on

the magnitude of the mirrors. With a mirror having an *aperture* of 6 feet, that is, the distance from one edge to the other, copper and silver are melted in a few minutes; and silicious stones and flints are softened and even melted.

In consequence of the high temperature produced in the foci of concave mirrors and of the facility with which combustibles may be ignited, they have been called *burning mirrors.* It is stated that Archimedes burnt the Roman vessels before Syracuse by means of such mirrors. Buffon constructed burning mirrors of

Fig. 172.

such power as to prove that the feat attributed to Archimedes was possible. The mirrors were made of a number of silvered plane mirrors about 8 inches long by 5 broad. They could be turned independently of each other in such a manner that the rays reflected from each coincided in the same point. With 128 mirrors and a hot summer's sun Buffon ignited a plank of tarred wood at a distance of 70 yards.

202. **Reflecting power of various substances.**—It has been seen that heat which falls upon a body is always divided into two

parts, one which is reflected on the surface, and the other which passes into the mass of the body, and raises its temperature. The quantities of heat thus absorbed, or reflected, vary in different substances; one set reflects much and the other little, which is expressed by saying that they have a great *reflecting power*; others, on the contrary, reflect very little heat, but absorb a great deal, and are therefore spoken of as having great *absorbing power*. It is clear that these properties are the inverse of each other, for every body which absorbs much heat can reflect but little, and conversely.

In order to compare the reflecting powers of various substances, Leslie took as a source of heat a tin plate cube full of boiling water, which he placed in front of a concave mirror (fig. 173). The rays emitted from this towards the reflector tended after reflection to

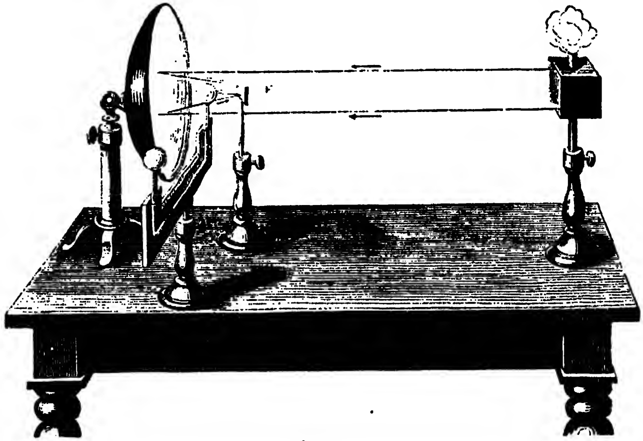

Fig. 173.

become concentrated on the focus F. In front of this were placed successively small square plates of paper, glass, metal, in short, of all the substances whose reflecting power was to be examined. As shown in the drawing, these rays, after a first reflection from the mirror, were reflected a second time from these plates, and finally impinged against the bulb of a differential thermometer. Now, as in this experiment the source of heat was the same, as was also the distance from the reflector, yet the thermometer indicated very various degrees of heat according to the material of which the small plates were formed. The temperature was highest when the

plate was made of polished brass, which metal is therefore the best reflector. The reflecting power of silver is only $\frac{9}{10}$ that of brass; that of tin $\frac{8}{10}$; of glass $\frac{1}{10}$. Water and lampblack were found to be destitute of reflecting power, for when the plates were coated with lampblack, or moistened with water, the thermometer indicated no increase in temperature, showing that it received no heat.

203. **Absorbing power.**—In order to compare the absorbent powers of various substances, Leslie arranged the experiment as shown in fig. 174. The source of heat and the reflector being the same as in the preceding experiment, the differential thermometer was placed in the focus where it received directly all the heat reflected by the mirror. The surface of the *focal* bulb was altered for each experiment by coating it successively with various materials, paper, tinfoil, gold, silver, copper, and leadfoil; it was also coated with a thin layer of lampblack; it was moistened, and so on. It

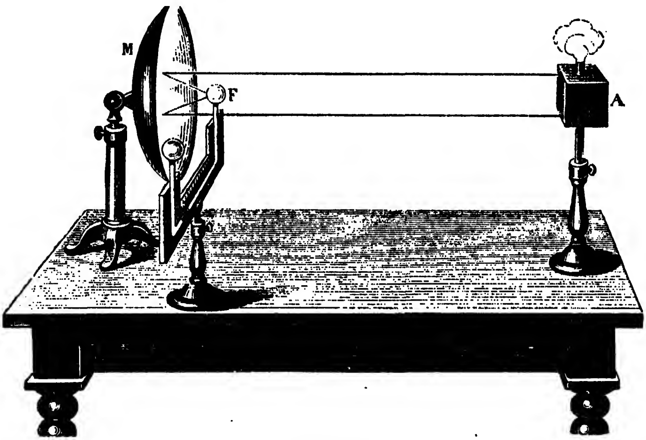

Fig. 174.

was thus found, that when the focal bulb was coated with lampblack, or with water, the thermometer indicated the highest temperatures; whence it was concluded that lampblack and water have the greatest absorbing power. The lowest temperature was exhibited when the bulb was coated with thin foil, more especially with brass; thus indicating that these substances absorb the least heat. The result was arrived at which could indeed be foreseen, that

those bodies which best reflect heat absorb it least ; and that, conversely, the best absorbents are the worst reflectors.

204. **Emissive power.**—The *emissive* or *radiating* power is the property bodies have of emitting more or less easily the heat they contain ; it is the inverse of the absorbing power.

Leslie compared the emissive powers of various bodies by means of the apparatus represented in fig. 174. The focal bulb of the thermometer was left uncoated, and the various substances were applied successively to the sides of the tin cube. One of them, for instance, was left in its ordinary condition ; the second was coated with lampblack ; to the third a sheet of white paper was fixed, and to the fourth a glass plate.

Turning first of all the blackened face towards the reflector, the thermometer indicated a considerable increase of temperature, thus showing that the cube sent much heat towards the reflector. Turning then successively the other faces towards the reflector, it was found that the paper side emitted less heat than the blackened face, but more than the glass side, which in turn emitted more than the tin side.

Working in this manner, Leslie then found that lampblack has the greatest emissive power, then paper, then ordinary glass, then the metals. The order of their emissive powers is thus the same as that of their absorbing powers. It is thus concluded that bodies which best absorb heat, also radiate best ; and Dulong and Petit have proved that for each substance the emissive power is in all cases proportional to the absorbing power.

205. **Causes which modify the reflecting, absorbing, and radiating powers.**—As the radiating and absorbing powers are equal, any cause which affects the one affects the other also. And as the reflecting power varies in an inverse manner, whatever increases it diminishes the radiating and absorbing powers, and *vice versâ*.

It has been already stated that these different powers vary with different bodies, and that metals have the greatest reflecting power, and lampblack the feeblest. In the same body these powers are modified by the degree of polish, the density, the thickness of the radiating substance, the obliquity of the incident or emitted rays, and, lastly, by the nature of the source of heat.

It has been assumed usually that the reflecting power increases with the polish of the surface, and that the other powers diminish therewith. But Melloni showed, that by scratching a polished metallic surface its reflecting power was sometimes diminished and

sometimes increased. This phenomenon he attributed to the greater or less density of the reflecting surface. If the plate had been originally hammered, its homogeneity would be destroyed by this process, the molecules would be closer together on the surface than in the interior, and the reflecting power would be increased. But if the surface is scratched the internal and less dense mass becomes exposed, and the reflecting power diminished. On the contrary, in a plate which has not been hammered and which is homogeneous, the reflecting power is increased when the plate is scratched, because the density at the surface is increased by the scratches.

The absorbing power varies with the inclination of the incident rays. It is greatest at right angles; and it diminishes in proportion as the incident rays deviate from the perpendicular direction. This is one of the reasons why the sun is hotter in summer than in winter, because, in the former case, the solar rays are less oblique.

The radiating power of gaseous bodies in a state of combustion is very weak, as is seen by bringing the bulb of a thermometer near a hydrogen flame, the temperature of which is very high. But if a platinum spiral be placed in this flame, it assumes the temperature of the flame, and radiates a considerable quantity of heat, as is indicated by the thermometer. It is for an analogous reason, that the flames of oil and of gas lamps radiate more than a hydrogen flame, in consequence of the excess of carbon which they contain, and which, not being entirely burned, becomes incandescent in the flame.

The absorbing power of a body is also influenced by the nature of the source of heat. Thus, for the same quantity of heat emitted, a surface coated with white lead absorbs twice as much if the heat comes from a cube filled with hot water as it does if the heat is that of a lamp. Lampblack, on the contrary, absorbs the same amount of heat whatever be the source.

It is usual to discriminate between *luminous heat*, such as that emitted by a lamp, or by a platinum wire raised to redness, and *obscure heat*, such as the heat of boiling water, or that of a copper plate at a temperature of 400° C.

206. **Applications.**—The property which bodies possess of absorbing, emitting, and reflecting heat, meets with numerous applications in domestic economy and in the arts. Leslie stated in a general manner, that white bodies reflect heat very well, and absorb very little, and that the contrary is the case with black substances. This principle is not generally true, as Leslie supposed; for example white lead has as great an absorbing power for non-luminous rays

as lampblack. It applies to powerful absorbents like cloth, cotton, wool, and other organic substances when exposed to luminous heat. Accordingly, the most suitable coloured clothing for summer is just that which experience has taught us to use, namely, white, for it absorbs less of the sun's rays than black clothing, and hence feels cooler.

The polished fire-irons before a fire are cold, whilst the black fender is often unbearably hot. If, on the contrary, a liquid is to be kept hot as long as possible, it must be placed in a brightly polished metallic vessel, for then, the emissive power being less, the cooling is slower. It is for this reason advantageous that the steam pipes, etc., of locomotives should be kept bright.

Snow is a powerful reflector, and, therefore, neither absorbs nor emits much heat. It is owing to its small emissive power that it protects from cold the ground and the plants which it covers; and owing to its small absorbing power it melts but slowly during a thaw. A branch of a tree, a bar of metal, a stone in the midst of a mass of snow, accelerate the fusion by the heat they absorb, and which they radiate about them.

In the Alps, the mountaineers accelerate the fusion of the snow by covering it with earth, which increases the absorbing power.

Metallic cooking vessels should be black and rough on the outside, for then their absorbing power is greater and they become heated more rapidly. Their bright and polished surface is purchased at the expense of combustible. This is what is seen in vessels of silver and of white porcelain. In common unglazed earthenware liquids are more rapidly heated, but also more rapidly cooled.

It is observed that the ripening of grape and other fruits is accelerated when they are placed in contact with a black wall (mortar mixed with lampblack). This arises from the fact, that from the great emissive power of the wall, as well as from its great absorbing power, it becomes more highly heated under the influence of the sun, and gives up more to the fruit.

CHAPTER IV.

CONDUCTING POWER OF BODIES.

207. **Conductivity of solids.**—In the phenomena of radiation which have been considered, heat is transmitted from one body to another through space, without raising the temperature of the spaces

through which it passes. It may also be propagated through the mass of a body by an internal radiation from molecule to molecule. This internal propagation in the mass of a body is called *conductivity*; and *good conductors* are those bodies which readily transmit heat in their mass, while those through which it passes with difficulty are called *bad conductors*.

Organic substances conduct heat badly. De la Rive and De Candolle have shown that woods conduct better in the direction of their fibres than in a transverse direction; and have remarked upon the influence which this feeble conducting power, in a transverse direction, exerts in preserving a tree from sudden changes of temperature, enabling it to resist alike a sudden abstraction of heat from within, and the sudden accession of heat from without. Tyndall

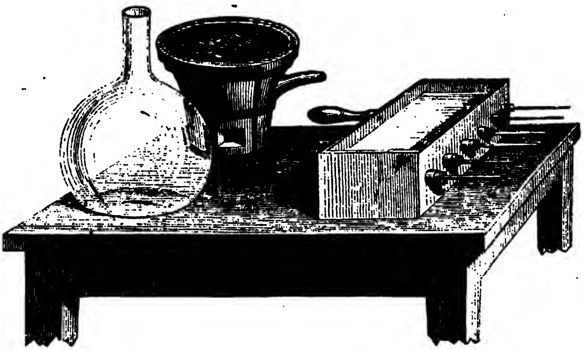

Fig. 175.

has also shown that this tendency is aided by the low conducting power of the bark, which is in all cases less than that of the wood.

Cotton, wool, straw, bran, etc., are all bad conductors.

In order to compare the conducting power or *conductivity* of different solids, Ingenhousz constructed the apparatus which bears his name, and which is represented in fig. 175. It is a metallic trough, in which, by means of tubulures and corks, are fixed rods of the same dimensions, but of different materials; for instance, iron, copper, wood, glass. These rods extend to a slight distance in the trough, and the parts outside are coated with wax, which melts at 61°. The box being filled with boiling water, it is observed that the wax melts to a certain distance on the metallic rods, while on the others there is no trace of fusion. The conducting power is

evidently greater in proportion as the wax has fused to a greater distance. The experiment is sometimes modified by attaching glass balls or marbles to the ends of the rods by means of wax. As the wax melts, the balls drop off, and this in the order of their respective conductivities. By these and other experiments it has been ascertained that metals are the best conductors, then marble, porcelain, brick, wood, glass.

208. **Conducting power of liquids. Manner in which they are heated.**—Liquids, with the exception of mercury, which is a metal, are all bad conductors of heat. They conduct so imperfectly that Rumford assumed water to be entirely destitute of conducting power. But its conductivity, though small, has been established beyond doubt, as well as that of other liquids, by the most accurate experiments.

From their small conducting power, liquids are not heated in the same manner as solids. If heat be applied to a solid, whether on the top, the bottom, or the sides, it is transmitted from layer to layer, and the whole mass becomes heated. This is not the case with a liquid; if it is heated at the top, the heat is only propagated with extreme slowness, and it cannot be completely heated. But if it be heated at the bottom, the temperature of the liquid rapidly rises. This, however, is not in virtue of conductivity, but by ascending and descending currents, which, in virtue of the mobility of the molecules, are produced throughout the whole mass of liquid.

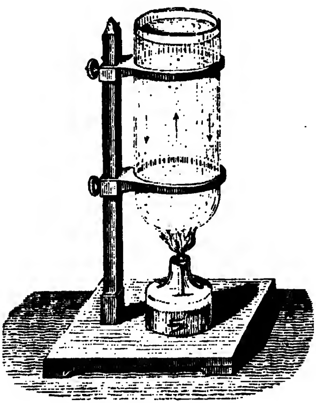

Fig. 176

The existence of these currents may be demonstrated by placing in the water a powder of approximately the same density, for instance, oak sawdust, and then gently heating this at the bottom. As the lower layers become heated they expand, while the upper layers, which are colder and therefore denser, sink and take the place of the first; these in their turn become heated, rise, and so on, until the entire mass is heated. These

currents are evident from the shavings which are seen to rise slowly in the centre, and to redescend near the edges.

209. **Conductivity of gases.**—Gases are extremely bad conductors of heat; but this cannot be easily demonstrated by experiment, owing to the extreme mobility of their particles. For so soon as they are heated in any part of their mass, expansions and currents are produced, in virtue of which the heated parts mingle with the cold ones; hence a general elevation of temperature, which we might be tempted to consider as due to conductivity. When, however, gases are hindered in their motion, their conductivity seems extremely small, as the following examples show.

210. **Applications.**—The greater or less conductivity of bodies meets with numerous applications. If a liquid is to be kept warm for a long time, it is placed in a vessel and packed round with non-conducting substances, such as shavings, straw, bruised charcoal. For this purpose water pipes and pumps are wrapped in straw at the approach of frost. The same means are used to hinder a body from becoming heated. Ice is transported in summer by packing it in bran, or folding it in flannel.

Double walls constructed of thick planks having between them any finely divided materials such as shavings, sawdust, dry leaves, etc., retain heat extremely well; and are likewise advantageous in hot countries, for they prevent its access. During the night the windows are opened, while during the day they are kept close. If a layer of asbestos, a very fibrous substance, is placed on the hand, a red-hot iron ball can be held without inconvenience. Red-hot cannon balls can be wheeled to the gun's mouth in wooden barrows partially filled with sand. Lava has been known to flow over a layer of ashes underneath which was a bed of ice, and the non-conducting power of the ashes has prevented the ice from fusion.

The clothes which we wear are not warm in themselves; they only hinder the body from losing heat, in consequence of their spongy texture and the air they enclose. The warmth of bed-covers and of counterpanes is explained in a similar manner. Double windows are frequently used in cold climates to keep a room warm—they do this by the non-conducting layer of air interposed between them. It is for the same reason that two shirts are warmer than one of the same material, but of double the thickness. Hence too the warmth of furs, eider down, etc.

That water boils more rapidly in a metallic vessel than in one of porcelain of the same thickness; that a burning piece of wood can

be held close to the burning part with the naked hand, while a piece of iron heated at one end can only be held at a great distance, are easily explained by reference to their various conductivities.

The sensation of heat or cold which we feel when in contact with certain bodies is materially influenced by their conductivity. If their temperature is lower than ours, they appear colder than they really are, because from their conductivity heat passes away from us. If, on the contrary, their temperature is higher than that of our body, they appear warmer from the heat which they give up at different parts of their mass. Hence it is clear why carpets, for example, are warmer than wooden floors, and why the latter are warmer than stone floors.

CHAPTER V.

MEASUREMENT OF THE EXPANSION OF SOLIDS, LIQUIDS, AND GASES.

211. **Expansion of solids.**—The expansion of bodies by heat being a general effect which exerts its influence on all bodies, and is continually changing their volume, it will be readily understood that the determination of the amount of this expansion is a problem of great importance, both in its purely scientific, as well as in its practical, aspects. We shall first describe the method of determining the expansion of solids. We have already seen that the expansion of solids may be either as regards the length or the volume. Hence the investigation of the expansion of solids may be divided into two parts, the first relating to *linear*, and the second to *cubical* expansion.

Linear expansion. In order to compare with each other the expansion of bodies, the elongation is taken which the unit of length undergoes when it is heated from zero to 1 degree, and this elongation is called the *coefficient of linear expansions.* The coefficients of a great number of substances were accurately determined towards the end of the last century by Lavoisier and Laplace. They took a bar of the substance to be determined, placed it in melting ice, and then accurately determined its length. Having placed it then in a bath of boiling water, they again measured its length. They then observed an elongation, which represented the total expansion for an increase of temperature of 100 degrees. This, divided by

100, gave the coefficient of linear expansion for one degree. In this manner the following numbers have been obtained.

Coefficients of linear expansion for 1° between 0° and 100° C.

White glass	0·00000861	Bronze	0·000018167
Platinum	0·00000884	Brass	0·000018782
Steel	0·00001079	Silver	0·000019097
Iron	0·00001220	Tin	0·000021730
Gold	0·00001466	Lead	0·000028575
Copper	0·00001718	Zinc	0·000029417

It will be seen from this table, that the coefficients of expansion are in all cases very small. Thus, when we say, that the coefficient of expansion of copper is about 0·000017, we mean that a rod of this metal when heated through 1 degree, will expand by 17 millionths of its length; that is to say, a rod of copper a million feet in length would be longer by 17 feet under these circumstances.

Cubical expansion. The *coefficient of cubical expansion* is the increase in volume for a temperature of one degree. Calculation shows that the coefficient of cubical expansion is three times its coefficient of linear expansion; and the coefficients may therefore be obtained by multiplying the above numbers by three.

212. **Applications of the expansion of solids.**—In the arts we meet with numerous examples of the influence of expansion. (i.) The bars of furnaces must not be fitted tightly at their extremities, but must, at least, be free at one end, otherwise, in expanding, they would exert sufficient force to split the masonry. (ii.) In making railways a small space is left between the successive rails, for, if they touched, the force of expansion would cause them to curve or would break the chairs. (iii.) Water pipes are fitted to one another by means of telescopic joints, which allow room for expansion. (iv.) If a glass is heated or cooled too rapidly it cracks; this arises from the fact that glass being a bad conductor of heat, the sides become unequally heated, and consequently unequally expanded, and the strain thereby produced is sufficient to cause a fracture.

When bodies have been heated to a high temperature, the force produced by their contraction on cooling is very considerable; it is equal to the force which is needed to compress or expand the material to the same extent by mechanical means. According to Barlow a bar of malleable iron a square inch in section is stretched $\frac{1}{10000}$ of its length by a weight of a ton; the same increase is ex-

perienced by about 9° C. A difference of 45° C. between the cold of winter and the heat of summer is not unfrequently experienced in this country. In that range a wrought iron bar, ten inches long, will vary in length by $\frac{1}{200}$ of an inch, and will exert a strain, if its ends are securely fastened, of fifty tons.

An application of this contractile force is seen in the mode of securing the tires on wheels. The tire being made red hot; and thus considerably expanded, is placed on the circumference of the wheel, and then cooled. The tire, when cold, embraces the wheel with such force as not only to secure itself on the rim, but also to press home the joints of the spokes into the felloes and naves. Another interesting application was made in the case of a gallery at the Conservatoire des Arts et Métiers in Paris, the walls of which had begun to bulge outwards. Iron bars were passed across the building, and screwed into plates on the outside of the walls. Each alternate bar was then heated by means of lamps, and when the bar had expanded, it was screwed up. The bars being then allowed to cool contracted, and in so doing drew the walls together. The same operation was performed on the other bars.

213. **Compensation pendulum.**—An important application of the expansions of metals has been made in *the compensation pendulum.* To understand the utility of such an arrangement, we must call to mind what has been said about pendulums; namely, that their oscillations are isochronous, that is, are made in equal times, and that their application to the regulation of clocks depends upon this property. But we have also seen that the duration of an oscillation depends on the length of the pendulum; the longer the pendulum the more slowly it oscillates, and, therefore, the shorter it is, the more rapidly does it oscillate. Hence a pendulum formed of a single rod terminated by a metal bob, *c*, as represented in fig. 52, could not be an exact regulator; for, as the temperature rises, it would elongate, and the clock would go slower: the exact opposite would take place when it contracted by cooling. These inconveniences have been remedied by taking the remedy from the cause of the evil.

For this purpose the pendulum rod consists of several metal bars arranged as represented in fig. 177. The rods, *a*, *b*, *c*, *d*, are of steel, and all expand on a downward direction when the temperature rises, thus making the bob sink. The rod, *d*, supporting the bob is fixed to a cross-piece *mn*, which in turn is fastened to two rods, *k* and *h*, which are connected to the piece *or*, and therefore cannot expand downwards, but only in an upward direction; they raise the

piece *mn*, and with it the bob. In order, therefore, that this latter shall neither raise nor sink, it is necessary that the upward expansion of the rods, *k* and *h*, shall exactly compensate the downward expansion of the rods, *a*, *b*, *c*, *d*.

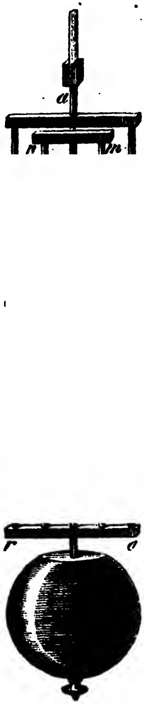

Fig. 177.

Brass being more expansible than steel, compensation is effected by taking the first metal for the rods, *h* and *k*, and the second for the rods, *a*, *b*, *c*, and *d*. The only condition necessary for compensation is that *the lengths of the two metals must be inversely as their coefficients of expansion.* That is to say, that if brass is two or three times as expansible as steel, its length must be one-half or one-third as much.

In fig. 177 the pendulum has been represented with a single frame of steel and one of brass; but in order to reduce the length, there are always at least two rows of steel and brass.

EXPANSION OF LIQUIDS.

214. **Absolute and apparent expansions.**—We have already seen that liquids are more expansible than solids (188), which is a consequence of their feeble cohesion; but their expansibility is far less regular, and the less so the nearer their temperature approaches that of their boiling point.

In solids two kinds of expansion have to be considered, the longitudinal and the cubical. Now it is clear that the latter is the only kind of expansion which can be observed in the case of liquids. The expansion may be either *real* or *apparent*. The former is the real increase in volume which a liquid assumes when it is heated; while the latter is that which the eye actually observes, that produced in the vessel containing the liquid. Thus in thermometers, when the liquid expands and rises in the stem, the apparent expansion is observed, which is less than the real or absolute expansion. For, while the mercury expands, the bulb of the thermometer does so too; its volume is greater, and hence the liquid does not rise so high in the stem as it would if the volume of the bulb were unaltered. If a flask of thin glass, provided with a capillary stem, the flask and part of the stem being filled with

some coloured liquid, be immersed in hot water, the column of liquid in the stem at first sinks, but then immediately after rises, and continues to do so until the liquid inside has the same temperature as the hot water. This first sinking of the liquid is not due to its contraction ; it arises from the expansion of the glass, which becomes heated before the heat can reach the liquid ; but the expansion of the liquid soon exceeds that of the glass, and the liquid ascends.

Hence since, whatever be the nature of the material in which a liquid is contained, it has some expansibility, and always expands with the liquid, the apparent expansion is the only one directly ob served in liquids.

The coefficient of expansion of a liquid is the increase which the unit of volume experiences for a rise in temperature of one degree. These coefficients greatly vary. In a glass vessel the apparent expansion of mercury is 1·5 parts in ten thousands ; that of water is 4·6 parts, that is, three times as great ; alcohol is still more expansible, for its coefficient is 11·6 parts in ten thousands.

215. **Maximum density of water.**—Water presents the remarkable phenomenon, that when its temperature sinks it contracts up to 4° ; but from that point, although the cooling continues, it expands up to the freezing point, so that 4° represent the point of greatest contraction of water, or, what is called, its point of maximum density.

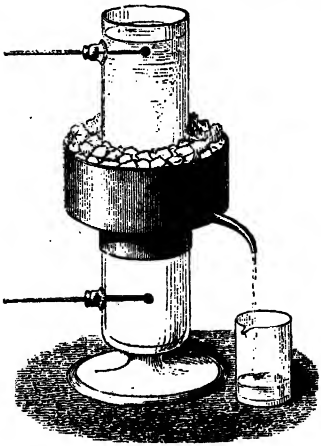

Fig. 178.

This phenomenon may be observed by comparing a water thermometer, one, that is to say, filled with water, with one of mercury ; both being exposed to gradually diminishing temperature.

Hope used the following method to determine the maximum density of water. He took a deep vessel, perforated by two lateral apertures, in which he fixed thermometers (fig. 178), and having filled the vessel with water at 0°, he placed it in a room at a temperature of 15°. As the layers of liquid at the sides of the vessel became heated they sank to the

bottom, and the lower thermometer marked 4°, while that of the upper one was still at zero. Hope then made the inverse experiment; having filled the vessel with water at 15°, he placed it in a room at zero. The lower thermometer having sunk to 4°, remained stationary for some time, while the upper one cooled down until it reached zero. Both these experiments prove that water is heavier at 4° than at 0°, for in both cases it sinks to the lower part of the vessel.

This phenomenon is of great importance in the economy of nature. In winter the temperature of lakes and rivers falls, from being in contact with the cold air, and from other causes, such as radiation. The colder water sinks to the bottom, and a continual series of currents goes on until the whole has a temperature of 4°. The cooling on the surface still continues, but the cooled layers being lighter remain on the surface, and ultimately freeze. The ice formed thus protects the water below, which remains at a temperature of 4°, even in the most severe winters, a temperature at which fishes and other inhabitants of the waters are not destroyed.

EXPANSION OF GASES.

216. **Value of the expansion of gases.**—Not merely are gases the most expansible of all bodies, but their expansion is the most regular. It was originally assumed, on the basis of Gay Lussac's experiments, that all gases expanded to the same extent for the same increase of temperature, that is, that they had all the same coefficient of expansion. It has, however, been established, that the coefficients of various gases do present slight differences. They are, however, so slight, that for all practical purposes they may be assumed to be the same; that is to say, 367 parts in a hundred thousand, or, in other words, that 100,000 volumes of air, or any other gas, when heated through 1 degree Centigrade, would become 100,367 volumes, or 1 volume in 273. This expansibility is about 13 times as great as that of water.

217. **Effects of the expansion of gases.**—The expansion of gases affords us numerous important applications, not merely in domestic economy, but also in atmospheric phenomena. Thus in our dwellings, when the air is heated and vitiated by the presence of a great number of persons, it expands and rises in virtue of its diminished density to the highest parts of rooms; and to allow this to escape, apertures are made in the cornice, while fresh and pure air enters by the joints of the doors and of the windows.

In theatres the spectators in the galleries are exposed to the highest temperature and the most impure air, while those near the orchestra respire in a purer air.

Draughts in chimneys are due to the expansion of air. Heated by the fire in the grate, the air rises in the chimney with a velocity which is greater the more it is expanded. Hence results a rapid current of air, which supports and quickens the combustion by constantly renewing the oxygen absorbed.

The expansion and contraction of air have a fortunate influence on the temperature of that part of the atmosphere in which we live. For when the ground is strongly heated by the sun's ardent rays, the layers of air in immediate contact with it tend to acquire the same temperature and to form a stifling atmosphere; but these layers, gradually expanding, rise in virtue of their diminished density; while the higher layers, which are colder and denser, gradually replace them. Thus the high temperature which would otherwise be produced in the lower regions is moderated, and never exceeds the limits which plants and animals can support.

The expansion and contraction produced in the atmosphere over a large tract of country are the cause of all winds, from the lightest zephyr to the most violent hurricane. These winds, which at times are so destructive, so capricious in their direction, and so variable in their intensity, not merely have the effect of mixing the heated and the cooler parts of the atmosphere, and of thus moderating extremes of temperature, but by driving away the vitiated atmosphere of our towns, and replacing it by pure air, they are one of the principal causes of salubrity; without them our cities would be centres of infection, where epidemics of all kinds would be permanent. Without winds clouds would remain motionless over the country where they were formed, the greater part of the globe would be condemned to absolute aridity, and neither rivers nor brooks would moisten the soil. But carried by the winds the clouds formed above the seas are transported to the centres of continents, where they fall as rain; and this having fertilised the soil, gives rise to the numerous rivers which fall into the ocean, thus establishing a continuous circulation from the seas towards the continents and from continents towards seas.

218. **Density of gases.**—The densities of solids and of liquids have been determined in reference to water (100); those of gases by comparison with air; that is, having taken as term of comparison, or *unity*, the weight of a certain volume of air, the weight

of the same volume of other gases is determined. But as gases are very compressible and very expansible, and as therefore their densities may greatly vary, they must be reduced to definite pressure and temperature. This is why *the temperature of zero* and *the pressure* 30 inches have been chosen.

Hence the relative *density* of a gas, or its *specific gravity*, is the relation of the weight of a certain volume of the gas to that of the same volume of air; both the gas and the air being at zero and at a pressure of 30 inches.

In order, therefore, to find the specific gravity of a gas, oxygen for instance, it is necessary to determine the weight of a certain volume of this gas, at a pressure of 30 inches, and a temperature of zero, and then the weight of the same volume of air under the same conditions. For this purpose a large globe of about two gallons capacity is used, like that represented in fig. 88, the neck of which is provided with a stopcock, which can be screwed to the air-pump. The globe is first weighed empty, and then full of air, and afterwards full of the gas in question. The weights of the gas and of the air are obtained by subtracting the weight of the exhausted globe from the weight of the globes filled, respectively, with air and gas. The quotient, obtained by dividing the latter by the former, gives the specific gravity of the gas. It is difficult to make these determinations at the same temperature and pressure, and therefore all the weights are reduced by calculation to zero, and the normal pressure of 30 inches.

In this manner the following densities have been found:

Air	1·0000	Oxygen	1·1056
Hydrogen . . .	0·0692	Carbonic oxide . . .	1·5290
Nitrogen . . .	0·9714	Chlorine	3·4400

From these numbers the lightest of gases, and therefore of all bodies, is hydrogen, whose density is less than $\frac{1}{14}$th of air.

CHAPTER VI.

CHANGES OF STATE OF BODIES BY THE ACTION OF HEAT.

219. **Fusion.**—In treating of the general effects of heat, we have seen that its action is not only to expand them, but to cause them to pass from the solid to the liquid state; or from the latter state

to the former, according as the temperature rises or falls; then from the liquid to the aëriform state, or conversely. These various changes of state we shall now investigate under the name of fusion, solidification, vaporisation, and liquefaction.

Fusion is the passage of a solid body to the liquid state by the action of heat. This phenomenon is produced when the force of cohesion which unites the molecules is balanced by the force of repulsion (4); but as the cohesive force varies in different substances, the temperature at which bodies melt does so likewise. For some substances this temperature is very low, and for others very high, as the following table shows:

Fusing points of certain substances.

Mercury	$-38{\cdot}8^\circ$	Sulphur	114°
Bromine	12·5	Tin	228
Ice	0	Bismuth	264
Butter	+33	Lead	335
Phosphorus	44	Zinc	422
Potassium	55	Antimony	450
Stearine	60	Silver	1000
White wax	65	Gold	1250
Sodium	90	Iron	1500

Some substances, however, such as paper, wood, wool, and certain salts, do not fuse at a high temperature, but are decomposed. Many bodies have long been considered *refractory*; that is, incapable of fusion; but, in proportion as it has been possible to produce higher temperatures, their number has diminished. Gaudin has succeeded in fusing rock crystal by means of a lamp fed by a jet of oxygen; and more recently Despretz, by combining the effects of the sun, the voltaic battery, and the oxy-hydrogen blowpipe, has melted alumina and magnesia, and softened carbon, so as to be flexible, which is a condition near that of fusion.

Some substances pass from the solid to the liquid state without showing any definite melting point; for example, glass and iron become gradually softer and softer when heated, and pass by imperceptible stages from the solid to the liquid condition. This intermediate condition is spoken of as the state of *vitreous fusion.* Such substances may be said to melt at the lowest temperature at which perceptible softening occurs, and to be fully melted when the further elevation of temperature does not make them more fluid; but no precise temperatures can be given as their melting points.

220. **Laws of fusion.**—It has been experimentally found, that the fusion of bodies is governed by the two following laws :

I. *Every substance begins to fuse at a certain temperature, which is invariable for each substance if the pressure be constant.*

II. *Whatever be the intensity of the source of heat, from the moment fusion commences, the temperature of the body ceases to rise, and remains constant until the fusion is complete.*

For instance, the melting point of ice is zero, and a piece of this substance exposed to the sun's rays, placed in front of a fire or over a lamp, could never be heated beyond this temperature. Exposure to a more intense heat would only accelerate the fusion, the temperature would remain at zero until the whole of the ice was melted.

221. **Latent heat.**—Since, during the passage of a body from the solid to the liquid state, the temperature remains constant until the fusion is complete, whatever be the intensity of the source of heat, it must be concluded that, in changing their condition, bodies absorb a considerable amount of heat, the only effect of which is to maintain them in the liquid state. This heat, which is not indicated by the thermometer, is called *latent heat*, or *latent heat by fusion*, an expression which, though not in strict accordance with modern ideas, is convenient from the fact of its universal recognition and employment.

An idea of what is meant by latent heat may be obtained from the following experiment. If a pound of water at 80° is mixed with a pound of water at zero, the temperature of the mixture is 40°. But if a pound of pounded *ice* at zero is mixed with a pound of water at 80°, the ice melts, and two pounds of water *at zero* are obtained. The pound of ice at zero is changed into a pound of water also at zero, but as the hot water is also lowered to this temperature, what has become of the 80° of heat it possessed ? They exist in the water which results from the ice ; their effect has neither been to heat it nor to expand, but simply to impart fluidity to it. Consequently, the mere change of a pound of ice to a pound of water at the same temperature requires as much heat as will raise a pound of water through 80°. This quantity of heat represents the *latent heat of the fusion* of ice, or the *latent heat of water.*

Every substance in melting absorbs a certain amount of heat, which, however, varies materially.

The enormous quantity of heat absorbed by ice in melting explains how it is that so long a time is required for thaw. And conversely it is owing to the latent heat of water, that even when

its temperature has been reduced to zero so long a time is required before it is entirely frozen. Before it can be so it must give out the heat which had been consumed in its liquefaction : it thus becomes a source of heat which retards the solidification. Faraday has calculated that the heat given out by a cubic yard of water in freezing is equal to that which would be produced by the combustion of a bushel of coals.

222. **Solidification.**—Those substances which are liquefied by heat revert to the solid state on cooling, and this passage from the liquid to the solid state is called *solidification*. If this solidification takes place at a low temperature it is frequently spoken of as *congelation*.

In all cases the phenomenon is subject to the following laws :

I. *Every body, under the same pressure, solidifies at a fixed temperature, which is the same as that of fusion.*

II. *From the commencement to the end of the solidification, the temperature of a liquid remains constant.*

Thus if lead begins to melt at 335°, melted lead in like manner when cooled down begins to solidify at 335°. Moreover, until it is completely solidified, the temperature remains constant at 335°. This arises from the fact, that the liquid in proportion as it solidifies restores the heat it had absorbed in being melted. The same phenomenon is observed whenever a liquid solidifies.

Many liquids, such as alcohol, ether, and bisulphide of carbon, do not solidify even at the lowest known temperature. Pure water solidifies at zero ; salt water at $-2\cdot5°$, olive and rape oils at $-6°$; linseed and nut oils at $-27°$.

Water presents the remarkable phenomenon, that when it solidifies and forms ice its volume undergoes a material increase. In speaking of the maximum density of water we have already seen that, on cooling, it expands from 4 degrees to zero ; it further expands on the moment of solidifying, or contracts on melting, by about 10 per cent. One volume of ice at 0° gives 0·908 of water at 0°, or 1 volume of water at 0° gives 1·102 of ice at the same temperature.

The increase of volume in the formation of ice is accompanied by an expansive force which sometimes produces powerful mechanical effects, of which the bursting of water pipes and the breaking of jugs containing water are familiar examples. The splitting of stones, rocks, and the swelling up of moist ground during frost, are caused by the fact that water penetrates into the pores and there becomes frozen.

The expansive force of ice was strikingly shown by some experi-

ments of Major Williams in Canada. Having quite filled a 13-inch iron bomb-shell with water, he firmly closed the touch-hole with an iron plug weighing 3 pounds, and exposed it in this state to the frost. After some time the iron plug was forced out with a loud explosion, and thrown to a distance of 415 feet, and a cylinder of ice 8 inches long issued from the opening.

From the expansion which water undergoes in freezing, it is clear that ice must be less dense than water; and this in fact is the case, for ice floats on the surface of water. In the polar seas, where the temperature is always very low, masses of floating ice are met with which are called ice-fields. They rise out of the sea to a height of 4 or 5 yards, and are immersed to a depth of 7 or 8 yards, and they frequently extend over 40 miles. True mountains of ice, or *icebergs*, are found floating on those seas; they have not the same extent, but attain very great heights.

Cast-iron, bismuth, and antimony expand on solidifying like water, and can thus be used for casting; but gold, silver, and copper contract, and hence coins of these metals cannot be cast, but must be stamped with a die.

223. **Crystallisation.**—When bodies pass slowly from the liquid to the solid state their molecules, instead of becoming grouped in a confused manner, generally acquire a regular order and arrangement, in virtue of which these bodies assume the geometrical shapes of cubes, pyramids, and prisms, etc., which are perfectly definite, and are known as *crystals*. Flakes of snow, when looked at under the microscope, ice in the process of formation, sugar candy, rock crystal, alum, common salt, and many other substances afford well-known instances of crystallisation.

Two methods are in use for crystallising substances; the *dry way* and the *moist way*. By the first method bodies are melted by heat, and then allowed to cool slowly. The vessel in which the operation is performed becomes lined with crystals, which are made apparent by inverting the vessel and pouring out the excess of liquid before the whole of it is melted. Sulphur, bismuth, and many other metals are thus easily crystallised. The second method consists in dissolving in hot water the substance to be crystallised, and then allowing it to cool slowly. The body is then deposited on the sides of vessels in crystals which are larger and better shaped the more slowly the crystallisation is effected. In this manner sugar candy and salts are crystallised.

224. **Solution.**—A body is said to *dissolve* when it becomes liquid in consequence of an affinity between its molecules and

those of a liquid. Gum arabic, sugar, and most salts dissolve in water.

During solution, as well as during fusion, a certain quantity of heat always becomes latent, and hence it is that the solution of a substance usually produces a diminution of temperature. In certain cases, however, instead of the temperature being lowered, it actually rises, as when caustic potass is dissolved in water. This depends upon the fact that two simultaneous and contrary phenomena are produced. The first is the passage from the solid to the liquid condition, which always lowers the temperature. The second is the *chemical* combination of the body dissolved with the liquid, and which, as in the case of all chemical combinations, produces an increase of temperature. Consequently, as the one or the other of these effects predominates, or as they are equal, the temperature either rises, or sinks, or remains constant.

225. **Freezing mixtures.**—The absorption of heat in the passage of bodies from the solid to the liquid state has been used to produce artificial cold. This is effected by mixing together bodies which have an affinity for each other, and of which one at least is solid, such as water and a salt, ice and a salt, or an acid and a salt. Chemical affinity accelerates the fusion, the portion which melts robs the rest of the mixture of a large quantity of sensible heat, which thus becomes latent. In many cases a very considerable diminution of temperature is produced.

If the substances taken be themselves first previously cooled down, a still more considerable diminution of temperature is occasioned.

Freezing mixtures are frequently used in chemistry, in physics, and in domestic economy. The portable ice-making machines which have come into use during the last few years, consist of a cylindrical metallic vessel divided into four concentric compartments. In the central one is placed the water to be frozen; in the next there is the freezing mixture, which usually consists of sulphate of sodium and hydrochloric acid; 6 pounds of the former and 5 of the latter will make 5 to 6 pounds of ice in an hour. The third compartment also contains water, and the outside one contains some badly conducting substance, such as cotton, to prevent the influence of the external temperature. The best effect is obtained when pretty large quantities, 2 or 3 pounds, of the mixture are used, and when they are intimately mixed. It is also advantageous to use the machines for a series of successive operations.

CHAPTER VII.

FORMATION OF VAPOURS. MEASUREMENT OF THEIR ELASTIC FORCE.

226. **Vapours.**—We have already seen (108) that *vapours* are the aëriform fluids into which substances, such as ether, alcohol, water, and mercury, are changed by the absorption of heat.

In respect to the property of disengaging vapours, liquids are divided into two classes, *volatile* liquids, and *fixed* liquids. The first are those which have a tendency to pass into the state of vapour, at the ordinary or even at lower temperatures; such, for instance, are water, ether, chloroform, alcohol, which rapidly disappear when exposed to the air in open vessels. To this class belongs a numerous family of liquids met with in nature, such as essence of turpentine, oil of lemons, of lavender, of thyme, of roses, etc.

Fixed liquids, on the contrary, are those which emit no vapour at any temperature; such, for instance, are the fat oils, as olive, rape, etc. When strongly heated these oils are decomposed, and give rise to gaseous products; but they do not emit vapours of the same nature as their own. There are some known as *drying oils*, which become thicker in the air; but this is in consequence of their having absorbed oxygen, and not in consequence of evaporation.

Some substances give vapours even in the solid state. Ice gives an instance of this, as is seen in dry cold winters, where the snow and ice quite disappear from the ground, without there having been any fusion. Camphor and odoriferous bodies, in general, present the same phenomenon.

227. **Elastic force of vapours.**—Vapours formed on the surface of a liquid are disengaged in virtue of their elasticity; but this force is generally far lower than the pressure of the atmosphere, and hence liquids exposed to the air only evaporate slowly.

The following experiment renders evident the elastic force of vapours. A bent glass tube has the shorter limb closed (fig. 179); this branch and part of the longer are filled with mercury. A drop of ether is then passed into the closed leg, which in virtue

of its lower density rises to the top of the tube at B. The tube thus arranged is immersed in a water bath at a temperature of about 45°. The mercury then sinks slowly in the short branch, and the space AB is filled with a gas which has all the appearance of air. This gas or aeriform fluid is nothing but the vapour of ether, whose elastic force CA counterbalances not only the pressure of the column of mercury, but also the atmospheric pressure exerted at C.

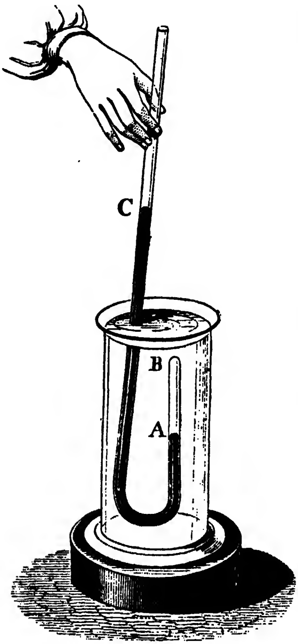

Fig. 179.

If the water in the vessel be cooled, or if the tube be withdrawn, the mercury gradually rises in the short leg, and the drop of liquid which seemed almost to have disappeared is re-formed. If, on the contrary, the water in which the tube is immersed be still more heated, the drop diminishes and the mercury descends further in the short leg; thus showing that fresh vapours are formed, and that the elastic force increases. This increase of tension with the temperature continues as long as any liquid remains to be vaporised.

The crackling of wood in fires is due to the increased tension of the vapours and gases formed in the pores of the wood during combustion. In roasting chesnuts it is usual to slit the outer skin; the object of this is to allow the vapour formed to escape, for otherwise it would acquire such a tension as to burst the chesnut and scatter the particles far and wide.

228. **Formation of vapours in a vacuum.**—In the previous experiment the liquid changed very slowly into the vaporous condition; the same is the case when a liquid is freely exposed to the air. In both cases the atmosphere is an obstacle to the vaporisation. In a vacuum there is no resistance, and the formation of vapours is instantaneous, as is seen in the following experiment. Four barometer tubes, filled with mercury, are immersed side by

side in the same trough (fig. 180). One of them, A, serves as a barometer, that is, only contains dry mercury, and a few drops of water, alcohol, and ether are respectively introduced into the tubes, B, C, D. When the liquids reach the vacuum a depression of the mercury is at once produced. But this depression cannot be produced by the weight of the liquid, for it is but an infinitely small fraction of the weight of the displaced mercury. Hence, in the case of each liquid, some vapour must have been formed whose elastic force has depressed the mercurial column, and as the depression is greater in the tube D than in the tube C, and greater in this than the tube B, it is concluded that, for the same temperature, the elastic force of ether is greater than that of alcohol vapour, and that this in turn has a greater elastic force than that of water. If the depression be measured by means of a graduated scale, it will be found that at a temperature of 20° the elastic force of ether is twenty-five times as great as that of water, and that of alcohol almost four times as great. From these experiments we obtain the two following laws for the formation of vapours :

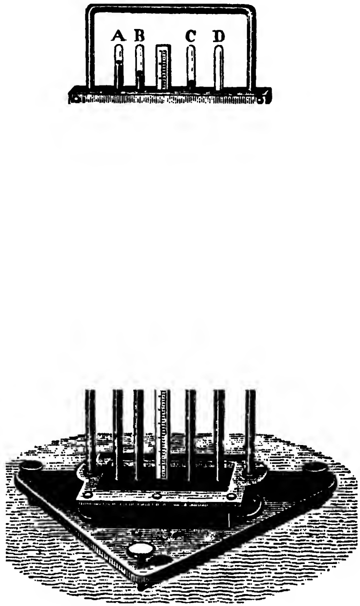

Fig. 180.

I. *In a vacuum all volatile liquids are instantaneously converted into vapour.*

II. *At the same temperature the vapours of different liquids have different elastic forces.*

229. **Limit to the formation and to the tension of vapours. Saturated space.**—The quantity of vapour which can be formed in a given space, whether at the ordinary or at higher temperatures,

is always limited. For instance, in the above experiment, the depression of mercury in each tube, B, C, D, is not stopped for want of liquid which might form fresh vapours, for care is taken always to add so much that a slight excess remains unvaporised. Thus, in the tube D, enough ether is left; yet we might wait weeks and years, and if the temperature did not increase, we should always see a portion of liquid in the tube, and the level of the mercury remain stationary. This shows that no new vapours can be formed in the tube, and at the same time that the elastic force of the vapour which is there cannot increase, which is expressed by saying that it has attained its *maximum tension.*

When a given space has acquired all the vapour which it can contain, it is said to be *saturated.* For instance, if in a bottle full of dry air a little water be placed, and the vessel be hermetically closed, part of the water will evaporate slowly, until the elastic force of the vapour formed holds in equilibrium the expansive force of that which still tends to form; the formation of vapour then ceases, and the space is saturated.

230. **The quantity of vapour which saturates a given space is the same whether this is vacuous, or contains air.**—For the same temperature the quantity of vapour necessary to saturate a given space is the same, whether the space is quite vacuous, or contains air or any other gas. In the above bottle, whether it be full of air, or has been exhausted, the total quantity which evaporates is exactly the same; the difference being that, in the first case, the evaporation only takes place slowly, while in the second case it is instantaneous. Yet, for the same space, whether it be vacuous or full of air, the quantity of vapour formed which corresponds to the state of saturation, varies with the temperature. The higher the temperature the greater is the quantity of vapour contained in a given space, the denser it is therefore; on the other hand, the lower the temperature, the less is the quantity required to saturate a given space.

The quantity of vapour present in air is very variable; but, spite of the abundant vaporisation produced on the surface of seas, lakes, and rivers, the air in the lower regions of the atmosphere is never saturated, even when it rains. This arises from the fact, that aqueous vapour being less dense than air, in proportion as it is formed, rises into the higher regions of the atmosphere, where, condensed by cooling, it falls as rain.

231. **Evaporation.—Causes which accelerate it.**—We have hitherto designated, under the general term of *vaporisation*, all production of vapour under whatever circumstances it takes place, whether slow or rapid, in air or in a vacuum; while the term *evaporation* is especially assigned to the slow formation of a vapour on the surface of a volatile liquid when it is exposed in the open air. It is in consequence of evaporation that the level gradually diminishes in a vessel full of water, and ultimately dries up if it is not fed by a spring. Owing to the same cause the earth moistened by rain dries up and ultimately hardens; that moist linen exposed in the air soon dries up. Several causes influence the rapidity of the evaporation of a liquid: the temperature; the quantity of the same vapour in the surrounding atmosphere; the renewal of this atmosphere; the extent of the surface of evaporation.

Influence of temperature. Heat being the agent of all evaporation, the higher the temperature the more abundant is the formation of vapour. This property is utilised in the arts to hasten and complete the drying of a large number of products which are exposed in *stoves*; that is to say, in chambers, the temperature of which is kept at 30, 40, 50, and even 60 degrees, and the air of which is continually renewed to allow the vapour formed to escape.

Influence of pressure. We have already seen that the pressure of the atmosphere is an obstacle to the disengagement of vapour, and it will thus be understood that when this pressure is diminished they ought to be formed more abundantly. This, in point of fact, is what takes place whenever liquids are removed from the pressure of the atmosphere. In sugar refineries, in order to concentrate the syrup (that is, to reduce the volume by removing part of the water they contain), they are placed in large spherical vessels; and then, by the aid of large air-pumps of special construction, and worked by steam engines, the air in the boilers is rarefied, which considerably accelerates the evaporation of water, and quickly brings the syrups to the wished-for degree of concentration.

Influence of the renewal of air. In order to understand the influence of the third cause, it is to be observed that no evaporation could take place in a space already saturated with vapour of the same liquid, and that it would reach its maximum in air completely freed from this vapour. It therefore follows that, between

these two extremes, the rapidity of evaporation varies according as the surrounding atmosphere is already more or less charged with the same vapour.

The effect of the renewal of this atmosphere is similarly explained; for if the air or gas, which surrounds the liquid, is not renewed, it soon becomes saturated, and evaporation ceases.

Thus it is that the wind, removing the layers of air which are in contact with the earth, soon dries up the roads and streets. Hence, too, it is that linen hung out to dry, does so far more rapidly on a windy than on a dry day.

The greater the extent of surface which a liquid presents to the air, the more numerous are the points from which vapour is disengaged. Hence the evaporation of a liquid should be effected in vessels which are wide and shallow. This is what is done in the process of extracting salt from sea water in salt gardens. The sea water is admitted into broad and shallow pits excavated in the ground. Under the influence of the solar heat the water evaporates slowly, and when its concentration has reached the point at which the liquid is saturated, the salt then begins to form on the surface and is raked off.

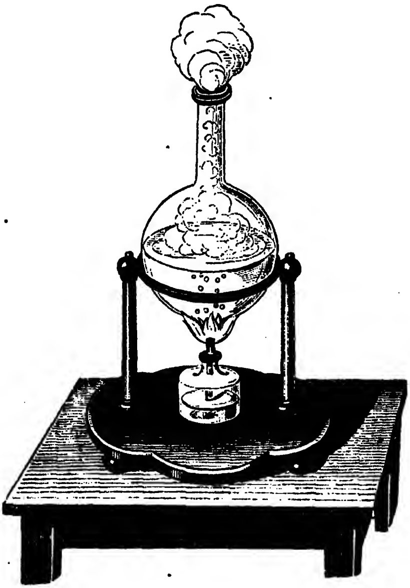

Fig. 181.

232. Ebullition.—*Ebullition*, or *boiling*, is the rapid production of elastic bubbles of vapour in the mass of a liquid itself.

When a liquid, water for example, is heated at the lower part of a vessel, the first bubbles are due to the disengagement of air

which had previously been absorbed. Small bubbles of vapour then begin to rise from the heated parts of the sides, but as they pass through the upper layers, the temperature of which is lower, they condense before reaching the surface. The formation and successive condensation of these first bubbles occasion the *singing* noticed in liquids before they begin to boil. Lastly, large bubbles rise and burst on the surface, and this constitutes the phenomenon of ebullition (fig. 181).

233. **Laws of ebullition.**—The laws of ebullition have been determined experimentally, and are as follows:

I. *The temperature of ebullition, or the boiling point, increases with the pressure.*

II. *For a given pressure ebullition commences at a certain temperature, which varies in different liquids, but which, for equal pressures, is always the same in the same liquid.*

III. *Whatever be the intensity of the source of heat, as soon as ebullition commences, the temperature of the liquid remains stationary.*

Thus, the boiling point of water under the ordinary atmospheric pressure being 100°, it could not be heated beyond that point, whatever the intensity of the source of heat; hence all the heat which passes from the source into the liquid is absorbed by the vapour disengaged. But, as this vapour is itself at 100°, we must conclude that this heat is not absorbed to raise the temperature of the vapour, but simply to produce it; that is, to change the substance from the liquid into the gaseous state, a phenomenon analogous to that which fusion presents (221). This disappearance of heat during ebullition will be subsequently investigated under the title of latent heat of vaporisation.

Boiling points under the pressure of an atmosphere.

Sulphurous acid	−10°	Turpentine	160°
Ether	37	Strong sulphuric acid	325
Bisulphide of carbon	48	Mercury	350
Bromine	63	Sulphur	447
Alcohol	78	Cadmium	860
Distilled water	100	Zinc	1040

234. **Causes which influence the boiling point.**—The boiling point of a liquid is affected by the substances in solution, by the

degree of pressure to which it is subjected, and by the nature of the vessels in which the boiling takes place.

The ebullition of a liquid is the more retarded, the greater the quantity of any substance it may contain in solution, provided that the substance be not volatile, or, at all events, be less volatile than the liquid itself. Water which boils at 100° when pure, boils at 109° when it is saturated with common salt; that is, when it has taken up as much of this salt as it can dissolve. Fatty matters

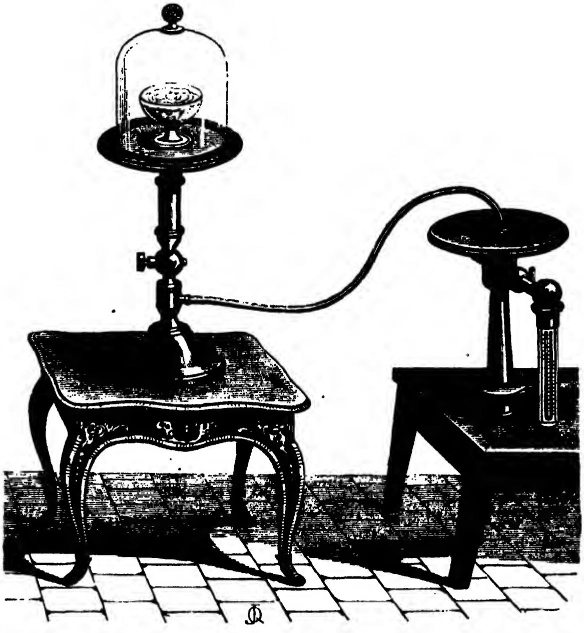

Fig. 182.

combined with water also raise its boiling point; hence it is that fat soup burns more severely than water.

Pressure. The degree of pressure to which a liquid is subjected has a most important influence on its boiling point. The greater the pressure the greater must be the tension, in order that the vapour may be disengaged, and therefore the higher the temperature. On the contrary, the less the pressure, the lower the temperature at which ebullition takes place. If the pressure of the atmosphere

be removed, water may be made to boil, even at the ordinary temperature. The experiment may be arranged in the manner represented in fig. 182. A glass cup containing water is placed under the bell-jar of an air-pump, or, in order that the experiment may be seen by a number of spectators, the bell is placed on a movable plate connected with the pump by a tube. When a vacuum is produced, or when the air is very rarefied, the water is seen to boil, evidently indicating a considerable disengagement of vapour. Yet the temperature of the liquid is not raised; the boiling is, on the contrary, a source of cold, owing to the heat, which becomes latent in the formation of vapours.

The influence of pressure on ebullition may further be illustrated by means of an experiment of Franklin's. The apparatus consists of a bulb and a tube, joined by a tube of smaller dimensions (fig. 183). The tube is drawn out, and the apparatus filled with water, which is then in great part boiled away by means of a spirit-lamp.

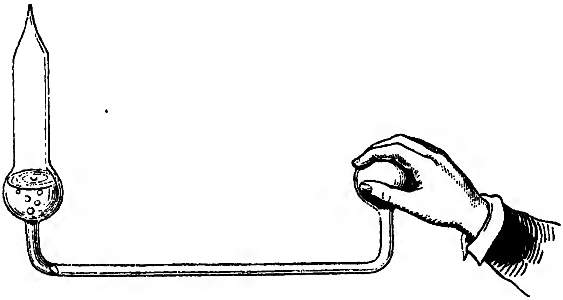

Fig. 183.

When it has been boiled sufficiently long to expel all the air, the tube is sealed. There is then a vacuum in the apparatus, or rather, there is only a pressure due to the tension of aqueous vapour, which at ordinary temperatures is very small. Consequently, if the bulb, *a*, be placed in the hand, as shown in the figure, the heat is sufficient to produce a pressure, which drives the water into the tube, *b*, and causes a brisk ebullition.

A paradoxical but very simple experiment also well illustrates the dependence of the boiling point on the pressure. In a glass flask water is boiled for some time, and when all air has been expelled by the steam, the flask is closed by a cork and inverted, as

shown in fig. 184. If the bottom is then cooled by a stream of cold water from a sponge, the water begins to boil again. This arises from the condensation of the steam above the surface of the water, by which a partial vacuum is produced.

As the pressure of air diminishes in proportion as we rise in the atmosphere, it will be seen from what has been said, that on high mountains water must boil at lower temperatures than on the sea level. This, in fact, is the case; on Mont Blanc, at a height of 15,800 feet, water boils at 84°; at Quito, at a height of 11,000 feet, at 90°; and at Madrid, the height of which is 3,000 feet, it boils at 97°. This diminution in the temperature of ebullition at great heights is a material obstacle to the preparation of food, for, at a temperature of 90°, the extraction of the nourishment and of the flavour is far more imperfect than under normal conditions.

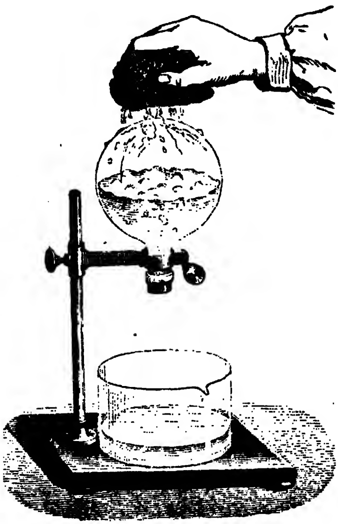

Fig. 184.

In deep mines, on the contrary, such as those of Cornwall and Lancashire, the reverse is the case; the pressure increases with the depth, and the boiling point is higher than at 100°.

Influence of the nature of the vessel on the boiling point. Gay-Lussac observed that water in a glass vessel required a higher temperature for ebullition than in a metal one. Taking the temperature of boiling water in a copper vessel at 100°, its boiling point in a glass vessel was found to be 101°; and if the glass vessel had been previously cleaned by means of sulphuric acid and of potass the temperature would rise to 105° or even to 106° before ebullition commenced. Whatever be the boiling point of water, the temperature of its vapour is uninfluenced by the substance of the vessels.

235. **Papin's digester.**—What has hitherto been said in reference to the formation of vapour has applied to the case of liquids

heated in open vessels. Only under these conditions can ebullition take place; for, in a closed vessel, since the vapours cannot escape into the atmosphere, their elastic force and their density continually increase, but that peculiarly rapid disengagement which constitutes boiling is impossible. There is, moreover, this difference between heating in an open and in a closed vessel; that, in the former case, the temperature can never exceed that of ebullition, while in a closed vessel it may be raised, so to speak, to an indefinite extent. Thus we have seen (233) that, in an open vessel, water cannot be heated beyond 100° C., all the heat imparted to it being absorbed by the vapours disengaged. But as this disengagement of vapour cannot take place in a closed vessel, water and the vapour may be raised to a far higher temperature than 100°. Yet this is not unattended with danger, from the very high tension which the vapour then assumes.

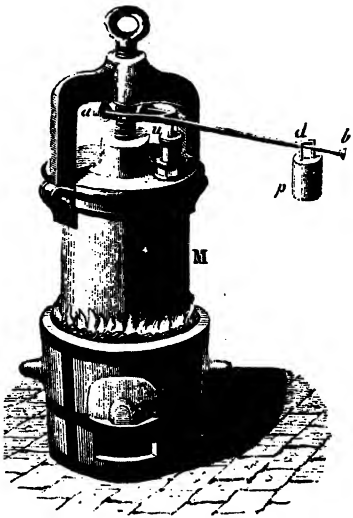

Fig. 185.

Figure 185 represents the apparatus used in physical lectures for the purpose of heating water in a closed vessel beyond 100 degrees. It is known as *Papin's Digester*. It consists of a cylindrical bronze vessel, M (fig. 185), provided with a cover, which is firmly fastened down by a screw. In order to close the vessel hermetically, sheet lead is placed between the edges of the cover and the vessel. At the bottom of a cylindrical cavity, which traverses a cylinder and tubulure, the cover is perforated by a small orifice in which there is a rod, *n*. This rod presses against a lever, *ab*, movable at *a*, and the pressure may be regulated by means of a weight, *p*, movable on this lever. The lever is so weighted, that when the tension in the interior is equal to six atmospheres, for example, the valve rises and the vapour escapes. The destruction of the apparatus is thus avoided, and the

mechanism, which will be described in speaking of the steam engine, has hence received the name of *safety valve.* The digester is filled about two-thirds with water, and is heated on a furnace. The water may thus be raised to a temperature far above 100°, and the tension of the vapour increased to several atmospheres, according to the weight on the lever.

The apparatus has received the name *digester*, from a Latin word signifying to dissolve, for the high temperature which water can acquire greatly increases its solvent power. Thus it is used to extract from bones the substance known as *glue*, which could not be accomplished at 100°.

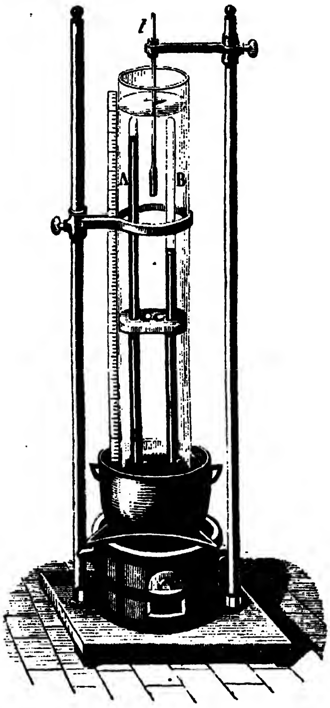

Fig. 186.

From the enormous elastic force which vapour may acquire in a closed vessel, it will be understood how important it is not to close tightly the vessel, in which water is contained for domestic purposes. Thus the hot water-bottles for heating the feet of invalids should be uncorked before being placed near the fire; for it might burst, or at any rate the cork might be driven out, and a more or less serious accident be caused. In like manner, when a locomotive stops, the steam must be allowed to escape; for otherwise, as it is continually being formed in the boiler without any being consumed in working the engine, it would ultimately acquire such an elastic force that an explosion would ensue.

236. **Measurement of the elastic force of aqueous vapour.**—The important applications which have been made of the elastic force of aqueous vapour, have led philosophers to measure with care the intensity of this force at various temperatures.

Dalton first measured the elastic force of aqueous vapour for

temperatures between 0° and 100°, by means of the apparatus represented in fig. 186. Two barometer tubes, A and B, are filled with mercury, and inverted in an iron bath full of mercury, and placed on a furnace. The tube, A, is an ordinary barometer tube, freed from air and moisture; but into the tube, B, is introduced a small quantity of water. The tubes are supported in a cylindrical vessel full of water, the temperature of which is indicated by the thermometer *t*. The bath being gradually heated, the water in the cylinder becomes heated too: the water which is in the tube B vaporises, and in proportion as the tension of its vapour increases, the mercury sinks. The depressions of the mercury corresponding to each degree of the thermometer, are indicated on the scale. Thus if, when the thermometer is at 70°, the mercury is 233 millimeters lower in the tube B than in the tube A, this shows that at 70° the tension of aqueous vapour is 233 millimeters; which amounts to saying that it exercises on the sides of the vessel which contains it a pressure equal to the weight of a column of mercury 233 millimeters in height.

By noting in the above manner the depression in the barometer, B, as compared with A, Dalton determined the elastic force of aqueous vapour from 0 to 100°. He found it to be 760 millimeters, or 29·92 inches; that is to say, an atmosphere.

Dulong and Arago determined the elastic force of aqueous vapour above 100° up to 24 pressures of 24 atmospheres. More recently Regnault measured the elastic force of aqueous vapour both above and below 100°; and from the researches of this experimenter the following table has been taken, in which the elastic forces at various temperatures are respectively measured by the height in millimeters of the column of mercury which they can balance.

Elastic force of aqueous vapour.

Temperatures	Tensions in millimeters	Temperatures	Tensions in millimeters
0	4·600	60	148·791
5	6·534	70	233·093
10	9·165	80	354·643
15	12.699	90	525.450
20	17·391	100	760·00
30	31.548	101	787·63
40	54·906	120	1520·00
50	91·982	160	4580·00

This table shows that the elastic force of aqueous vapour increases far more rapidly than the temperature. Thus at 50° the tension is only 91·9 millimeters; while at 100° degrees, that is to say, double the temperature, the tension is eight times as great.

237. **Latent heat of vapour.**—In speaking of ebullition we have seen that, from the moment a liquid begins to boil, its temperature ceases to rise whatever be the intensity of the source of heat. It follows that a considerable quantity of heat becomes absorbed in ebullition, the only effect of which is to transform the body from the liquid to the gaseous condition. And conversely, when a saturated vapour passes into the state of liquid, it gives out an amount of heat.

These phenomena were first observed by Black, and he described them by saying that, during vaporisation, a quantity of sensible heat became latent, and that the latent heat again became free during condensation. The quantity of heat which a liquid must absorb in passing from the liquid to the gaseous state, and which it gives out in passing from the state of vapour to that of liquid, is spoken of as the *latent heat of evaporation.*

The analogy of these phenomena to those of fusion will be at once seen. The modes of determining them need not be described; but the following results which have been obtained for the latent heats of evaporation of a few liquids may be here given:—

Water	540	Bisulphide of carbon . .	87
Alcohol	208	Turpentine	74
Ether	90	Bromine	46

The meaning of these numbers is, in the case of water, for instance, that it requires as much heat to convert a pound of water from the state of liquid at the boiling point to that of vapour at the same temperature, as would raise a pound of water through 540 degrees, or 540 pounds of water through one degree; or that the conversion of one pound of vapour of alcohol at 78° into liquid alcohol of the same temperature would heat 208 pounds of water through *one* degree.

238. **Cold due to evaporation.**—Whatever be the temperature at which a vapour is produced, an absorption of heat always takes place. If, therefore, a liquid evaporates, and does not receive from without a quantity of heat equal to that which is expended in producing the vapour, its temperature sinks, and the cooling is greater in proportion as the evaporation is more rapid.

This may become a source of very great cooling. Thus if a few drops of ether be placed in the hand, and this be agitated to accelerate the evaporation, great cold is experienced. With liquids which are less volatile than ether, like alcohol and water, the same phenomenon is produced, but the cooling is less marked.

On coming out of a bath, and more especially in the open air and with some wind, a very sharp cold is experienced, due to the vapour formed on the surface of the body. Moist linen is cold and injurious, because it withdraws from the body the heat necessary for evaporation.

The cooling effect produced by a wind or draught does not necessarily arise from the wind being cooler, for it may, as shown by the thermometer, be actually warmer; but arises from the rapid evaporation it causes from the surface of the skin. We have the feeling of oppression, even at moderate temperatures, when we are in an atmosphere saturated by moisture in which no evaporation takes place.

The cooling produced by the use of fans is due to the increased evaporation they produce. The freshness occasioned by watering the streets is also an effect of evaporation.

The cold produced by evaporation is used in hot climates to cool water by means of *alcarrazas*. These are porous earthen vessels, through which water percolates, so that on the outside there is a continual evaporation, which is accelerated when the vessels are placed in a current of air. For the same reason wine is cooled by wrapping the bottles in wet cloths and placing them in a draught.

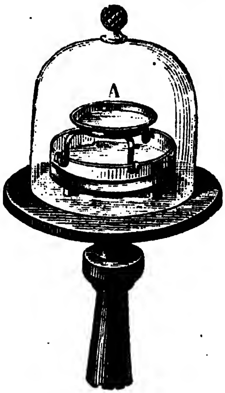

Fig. 187.

239. **Water and mercury frozen in a vacuum.**—From the great quantity of heat which disappears when a liquid is converted into vapour it will be seen that by accelerating the evaporation we have a means of producing intense cold. We have seen that liquids vaporise more rapidly the lower the pressure. Hence, if a vessel containing water be placed in a space from which the air is exhausted, it should cool very rapidly.

Leslie succeeded in freezing water by means of rapid evaporation. Under the receiver of the air-pump is placed a vessel containing

strong sulphuric acid, a substance which has a great affinity for water, and above it a thin, shallow, porous capsule (fig. 187) containing a small quantity of water. By exhausting the receiver the water begins to boil, and since the vapours are absorbed by the sulphuric acid as fast as they are formed, a rapid evaporisation is produced, which quickly effects the freezing of the water.

By using liquids more volatile than water, more particularly liquid sulphurous acid, which boils at $-10°$, a degree of cold is obtained sufficiently intense to freeze mercury. The experiment may be made by covering the bulb of a thermometer with cotton wool, and after having moistened it with liquid sulphurous acid, placing it under the receiver of the air-pump. When a vacuum is produced the mercury is quickly frozen.

Thilorier, by directing a jet of liquid carbonic acid on the bulb of an alcohol thermometer, obtained a cold of $-100°$ without freezing the alcohol. With a mixture of solid carbonic acid, liquid protoxide of nitrogen and ether, M. Despretz obtained a sufficient degree of cold to reduce alcohol to the viscous state.

By means of the evaporation of bisulphide of carbon the formation of ice may be illustrated without the aid of an air-pump. A little water is dropped on a small piece of wood, and a capsule of thin copper foil, containing bisulphide of carbon, is placed on the water. The evaporation of the bisulphide is accelerated by means of a pair of bellows, and after a few minutes the water freezes round the capsule, so that the latter adheres to the wood.

CHAPTER VIII.

LIQUEFACTION OF VAPOURS AND GASES.

240. **Liquefaction of vapours.**—The *liquefaction* or *condensation* of vapours is their passage from the aëriform to the liquid state. Condensation may be due to three causes—cooling, compression, or chemical affinity.

When vapours are condensed, their latent heat becomes free, that is, it affects the thermometer. This is readily seen when a current of steam at 100° is passed into a vessel of water at the ordinary temperature. The liquid becomes rapidly heated, and soon reaches 100°. The quantity of heat given up in liquefaction is equal to the quantity absorbed in producing the vapour.

Liquefaction by chemical affinity.—The affinity of certain substances for water is so great as to condense the vapours in the atmosphere, even when they are far from their point of saturation. Thus, when highly hygroscopic substances, such as quicklime, potass, sulphuric acid, are exposed in the air, they always absorb aqueous vapour. Certain varieties of common salt exposed to the air absorb and condense so much aqueous vapour as to become liquid. Many other salts have the same property, and are hence called *deliquescent salts.*

Liquefaction by pressure.—Let us suppose a vessel containing aqueous vapour, a cylinder for instance, and in this cylinder a piston which can be depressed at will, like that represented in fig. 4 page 9. As the vapour is not at first in a state of saturation when the piston is depressed, it behaves like a true gas, the pressure increasing its elastic force and density without liquefying it. But the more the piston is depressed the smaller does the volume of the vapour become, and a point is ultimately reached at which the vapour present is just sufficient to saturate the space. From this point the slightest increase of pressure causes a portion of vapour to pass into the liquid state, and the liquefaction continues as long as the excess of pressure lasts; so that if the piston descends to the bottom of the cylinder all the vapour is condensed. In this experiment it is to be observed, that when once saturation is attained, provided there is no air in the cylinder, the resistance to the depression of the piston does not increase in proportion as it descends, which arises from the condensation of the vapour, and confirms what was previously said as to the maximum tension of vapour in a state of saturation.

Liquefaction by cooling.—Cooling, as well as pressure, only causes vapours to liquefy when they are in a state of saturation. But when once a given space is saturated, the slightest lowering of temperature takes from the vapours the heat which gives them their fluidity, the attraction between the molecules preponderates, they agglomerate, forming extremely small droplets, which float in the air and are deposited on the surrounding bodies.

Vapours are ordinarily condensed by cooling. Thus, the vapours exhaled from the nose and mouth of animals first saturate the colder air in which they are disengaged, and then condense with a cloud-like appearance. It is owing to the same phenomenon that the vapours become visible which are disengaged from boiling water, those which rise from chimneys, the fogs formed above

rivers, and so forth. All these vapours are more apparent in winter than in summer, for then the air is colder, and the condensation more complete.

In cold weather, the windows in heated rooms are seen to become covered with dew on the inside. The air of these rooms is in general far from being saturated with vapour, but the layers of air in immediate contact with the windows become colder; and as the quantity of vapour necessary to saturate a given space is less, the colder this space, a moment is reached at which the air in contact with the windows is saturated, and then the vapours they contain are quickly deposited. In a time of thaw, when the air is hotter on the outside than on the inside, the deposit is formed on the outside. To the same cause is due the deposit of moisture formed on walls, which is expressed by saying that they *sweat*; an unsuitable expression, for the moisture does not come from the walls but from the atmosphere. The walls are colder than the air, and they lower the temperature of the layers in contact with them, and condense the vapours. A similar effect is produced when in summer a bottle of wine is brought from the cellar, or when a glass is filled with cold water; a deposit of dew is formed on the surface of these vessels. The same phenomenon does not occur in winter, for then the temperature of the atmosphere being the same as that of the bottle, or even lower, the layers of air in immediate contact with it are not cooled.

241. **Heat disengaged during condensation.**—It has been seen that any liquid in vaporising absorbs a quantity of heat. This heat is not destroyed, for in the converse change it reappears in the *sensible* state; that is to say, capable of acting on our organs and on the thermometer. For instance, we know that a pound of water absorbs in vaporising 540 units of heat (237); that is to say, a quantity of heat necessary to raise 540 pounds of water from 0° to 1°: conversely, a pound of water at 100°, which is liquefied and gives a pound of water at 100°, causes 540 units to pass from the latent to the sensible state, an amount of heat which is utilised in heating by steam.

242. **Application to heating by steam.**—The quantity of heat which becomes free when aqueous vapour is condensed is utilised in the arts for heating private houses, hot-houses, and public buildings. Steam is produced in boilers like those used in steam engines, and passes from thence into metallic tubes concealed behind the wainscot, or into columns which serve at the same time as ornaments

for rooms. The steam condensing in these tubes gives up a considerable quantity of heat, which they impart to the surrounding air.

243. **Distillation. Stills.**—*Distillation* is an operation by which volatile liquid may be separated from substances which it holds in solution, or by which two liquids of different volatilities may be separated. The operation depends on the transformation of liquids into vapours by the action of heat, and on the condensation of these vapours by cooling.

The apparatus used in distillation is called a *still*. Its form may vary greatly, but consists essentially of three parts; 1st, the *body*,

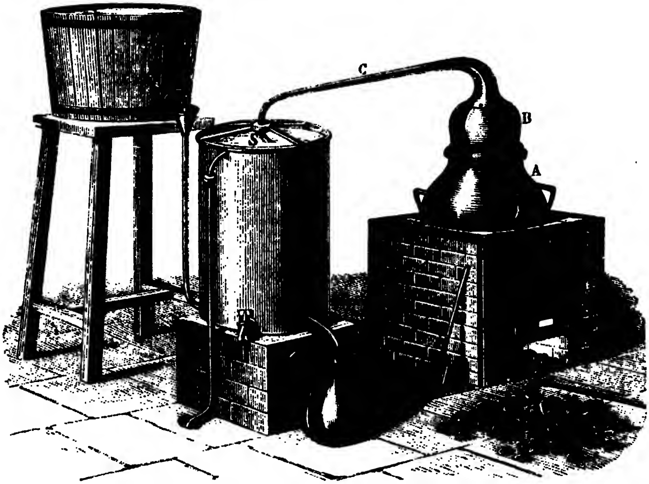

Fig. 188.

A (fig. 188), a copper vessel containing the liquid, the lower part of which fits in the furnace; 2nd, the *head*, B, which fits on the body, and from which a lateral tube, C, leads to, 3rd, the *worm*, S, a long spiral tin or copper tube, placed in a cistern kept constantly full of cold water. The object of the worm is to condense the vapour, by exposing a greater extent of cold surface.

To free ordinary well water from the many impurities which it contains, it is placed in a still and heated. The vapours disengaged are condensed in the worm, and the distilled water arising from the condensation is collected in the receiver, D. The vapours in condensing rapidly heat the water in the cistern, which must,

therefore, be constantly renewed. For this purpose a continual supply of cold water passes into the bottom of the cistern, while the lighter heated water rises to the surface, and escapes by a tube in the top of the cistern.

Brandy is obtained from wine by means of distillation. Wine, consisting essentially of water, alcohol, and colouring matter, when heated in a still to a temperature between 78° and 100°, the alcohol, which boils at 78°, vaporises, while water, which only boils at 100°, remains behind, or at all events only passes over in small quantity. The liquid resulting from this distillation, is brandy, which is essentially a mixture of alcohol and water.

244. **Liquefaction of gases.**—We have already seen that a saturated vapour, the temperature of which is constant, is liquefied by increasing the pressure, and that, the pressure remaining constant, it is brought into the liquid state by diminishing the temperature.

Unsaturated vapours behave in all respects like gases. And it is natural to suppose, that what are ordinarily called *permanent gases* are really unsaturated vapours. For the gaseous form is accidental, and is not inherent in the nature of the substance. At ordinary temperatures sulphurous acid is a gas, while in countries near the poles it is a liquid; in temperate climates ether is a liquid, at a tropical heat it is a gas. And just as unsaturated vapours may be brought to the state of saturation and then liquefied by suitably diminishing the temperature or increasing the pressure, so by the same means gases may be liquefied. But as they are mostly very far removed from this state of saturation great cold and pressure are required. Some of them may indeed be liquefied either by cold or by pressure; for the majority, however, both processes must be simultaneously employed. Few gases can resist these combined actions, and probably those which have not yet been liquefied, hydrogen, oxygen, nitrogen, binoxide of nitrogen, and carbonic oxide, would become so if submitted to a sufficient degree of cold and pressure.

One of the most remarkable experiments on the liquefaction of gases is that made by Thilorier to liquefy and solidify carbonic acid. The principle of the method was first devised and applied by Faraday. The apparatus consists of two cast iron cylinders with very thick sides, of 5 to 6 quarts capacity. They are hermetically closed, and are connected by means of a leaden tube. In one of these cylinders, called the generator, are placed the substances by whose chemical action carbonic acid is evolved

These are ordinarily bicarbonate of soda and sulphuric acid. The second cylinder, called the *receiver*, is empty; and the gas disengaged by the chemical action in the generator distils over, and, as the receiver is colder, it condenses in virtue of its increasing pressure. As much as two quarts of liquid carbonic acid have thus been prepared.

At a temperature of 15 degrees the tension of the compressed gas in the cylinders is not less than 50 atmospheres; a pressure which would burst the vessels if they were not solidly constructed. An accident of this kind happened some years ago, and caused the death of Thilorier's assistant.

To obtain solid carbonic acid, the receiver is provided with a stopcock attached to a tube, which dips in the liquid acid. On opening this stopcock the liquid acid driven by pressure jets out; passing then from a tension of 50 atmospheres down to a single one, a part of the liquid volatilised; and in consequence of the heat absorbed by this evaporation, the rest is so much cooled as to solidify in white flakes like snow, or anhydrous phosphoric acid.

Solid carbonic acid evaporates very slowly. By means of an alcohol thermometer its temperature has been found to be about $-90°$. A small quantity placed on the hand does not produce the sensation of such great cold as might be expected. This arises from the imperfect contact. But if the solid be mixed with ether the cold produced is so intense, that when a little is placed on the skin all the effects of a severe burn are produced. A mixture of these two substances solidifies four times its weight of mercury in a few minutes. When a tube containing liquid carbonic acid is placed in this mixture the liquid becomes solid, and looks like a transparent piece of ice.

CHAPTER IX.

SPECIFIC HEAT. CALORIMETRY.

245. **Calorimetry. Thermal unit.**—The object of calorimetry is to measure the *quantity of heat* which a body parts with or absorbs when its temperature sinks or rises through a certain number of degrees, or when it changes its condition.

Quantities of heat may be expressed by any of its directly measurable effects, but the most convenient is the alteration of temperature, and quantities of heat are usually defined by stating the

extent to which they are capable of raising a known weight of a known substance, such as water.

The unit chosen for comparison, and called the *thermal unit*, is not everywhere the same. In France it is the quantity of heat necessary to raise the temperature of *one* kilogramme of water through *one* degree Centigrade; this is called a *calorie*. In this book we shall adopt, as a thermal unit, *the quantity of heat necessary to raise one pound of water through one degree Centigrade:* 1 *calorie* = 2·2 thermal units, and 1 thermal unit = 0·45 *calorie*.

246. **Specific heat.**—When equal weights of two different substances at the same temperature placed in similar vessels are subjected for the same length of time to the heat of the same lamp, or are placed at the same distance in front of the same fire, it is found that their temperatures will vary considerably; the mercury will be much hotter than the water. But as from the conditions of the experiment, they have each been receiving the same amount of heat, it is clear that the quantity of heat which is sufficient to raise the temperature of mercury through a certain number of degrees will only raise the temperature of the same quantity of water through a less number of degrees; in other words, that it requires more heat to raise the temperature of water through one degree than it does to raise the temperature of mercury by the same extent. Conversely, if the same quantities of water and of mercury at 100° C. be allowed to cool down to the temperature of the atmosphere, the water will require a much longer time for the purpose than the mercury: hence in cooling through the same number of degrees, water gives out more heat than does mercury.

It is readily seen that all bodies have not the same specific heat. If a pound of mercury at 100° is mixed with a pound of water at zero, the temperature of the mixture will only be about 3°. That is to say, that while the mercury has cooled through 97°, the temperature of the water has only been raised 3°. Consequently, the same weight of water requires about 32 times as much heat as mercury does to produce the same elevation of temperature.

If similar experiments are made with other substances it will be found that the quantity of heat required to effect a certain change of temperature is different for almost every substance, and we speak of the *specific heat* or *calorific capacity* of a body as the quantity of heat which it absorbs when its temperature rises through a given range of temperature, from zero to 1° for example, compared with the quantity of heat which would be absorbed under the same cir-

cumstances, by the same weight of water. In other words, water is taken as the standard for the comparison of specific heats. Thus, to say that the specific heat of lead is 0·0314, means that the quantity of heat which would raise the temperature of any given quantity of lead through 1° C. would only raise the temperature of the same quantity of water through 0·0314.

247. **Determination of the specific heats of solids and of liquids.**—Three methods have been employed for determining the specific heats of bodies : (i.) the method of melting ice, (ii.) the method of mixtures, and (iii.) that of cooling. In the latter, the specific heat of a body is determined by the time which it takes to cool through a certain temperature.

Method of the fusion of ice.—This method of determining specific

Fig. 189.

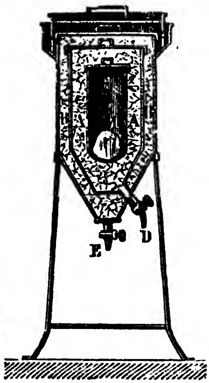

Fig. 190.

heats is based on the fact that to melt a pound of ice, 80 thermal units are necessary, or more exactly 79·25. The substance to be determined is raised to a known temperature, 100° for instance, and is then rapidly placed in ice. In cooling from 100° to zero, the body melts a certain quantity of ice, which is collected in the form of water. From the weight of this water, from that of the body, and from the number of degrees through which it is cooled, the specific heat may be readily calculated.

To facilitate the execution of this method Lavoisier and Laplace devised an apparatus which is called the *ice calorimeter*. Fig. 189 gives a perspective view of it, and fig. 190 represents a section. It

consists of three concentric tin vessels, M, A, B, each with covers of the same material : in the central one is placed the body M, whose specific heat is to be determined, while the two others, A and B, are filled with pounded ice. The ice in the compartment A is melted by the heated body, and the water resulting from the liquefaction runs off by the stopcock D, and is collected in a vessel; the ice in the compartment B cuts off the heating influence of the surrounding atmosphere. The stopcock E gives issue to the water which arises from the liquefaction of the ice in B.

Method of mixtures.—In determining the specific heat of a solid body by this method, it is weighed and raised to a known temperature, by keeping it, for instance, for some time in a closed space heated by steam; it is then immersed in a mass of cold water, the weight and temperature of which are known. The water becomes heated by the heat given up by the body in cooling, and both are ultimately at the same temperature. From this common temperature, from the respective weights of the water and of the substance, and lastly from their temperatures at the time of mixture, the specific heat of the body is deduced by a simple calculation.

Substances.	Specific heats.	Substances.	Specific heats.
Water	1·0000	Zinc	0·0955
Turpentine	0·4259	Copper	0·0951
Wood charcoal	0·2411	Silver	0·0570
Sulphur	0·2025	Tin	0·0562
Graphite	0·2018	Antimony	0·0507
Thermometer glass	0·1976	Mercury	0·0333
Phosphorus	0·1895	Gold	0·0324
Diamond	0·1469	Platinum	0·0324
Iron	0.1138	Lead	0·0314
Nickel	0·1086	Bismuth	0·0308

It will be seen from the following table that water and oil of turpentine have a much greater specific heat than that of other substances, and more especially than the metals. It is from its great specific heat that water requires a long time in being heated or cooled ; and that, for the same weight and temperature, it absorbs or gives out far more heat than other substances. This double property is applied in the hot water apparatus, and it plays a most important part in the economy of nature.

CHAPTER X.

STEAM ENGINES.

248. **Invention of the steam engine.**—Steam engines are undoubtedly the most important of the applications of the physical sciences to the arts. Based on the very great elastic force which aqueous vapour assumes at a high temperature (236), and on the condensation of this vapour by cooling (240), steam engines have created, in a small volume and at small expense, very considerable motive powers.

Their importance has caused much discussion and investigation as to their inventor, or rather inventors; for it is only by the successive efforts of several men of genius that these machines have attained their present simplicity and precision.

The history of the steam engine commences with Hero, the inventor of the fountain which bears his name, who invented, nearly two thousand years ago, a steam tourniquet, known as the *eolipyle*, analogous to the hydraulic tourniquet. The names of Salomon of Caux, and then of the Marquis of Worcester, are mentioned in the history of the steam engine.

Denis Papin, a French physicist, to whom is due the apparatus already described (235), was the first who caused a piston to ascend in a vertical cylinder closed at the bottom and open at the top by means of the elastic force of steam, and to descend by condensing this vapour by cooling; so that the piston which descended in virtue of atmospheric pressure had an up and down motion in the cylinder, which is still the principle of all steam engines. Papin, who was a Protestant, was obliged to fly from France in consequence of the revocation of the Edict of Nantes, and the description and plan of his machine was published in Germany in 1690. He even made a model large enough to move a boat by means of paddle-wheels. In this model there was water underneath the piston at the bottom of the cylinder. When a furnace was placed under this, the water vaporised, and the elastic force raised the piston; when it was at the top of its course the furnace was withdrawn; the cylinder cooling the vapour was condensed, and the piston sank.

In 1705 Newcomen and Cawley constructed a steam engine, or 'fire-pump,' as it was then called, the object of which was to drain mines. In this engine the steam was produced separately in a boiler below the cylinder containing the piston. The condensation also was effected by cold water being injected into the cylinder through a cock. This was opened when the piston was to descend, and was closed after the descent; a second one was opened through which steam entered, and so on. But the sides of the cylinder being cooled by this injection of cold water, the steam which followed it was partially condensed, until the sides were again heated: there was thus a loss of steam, and therefore of combustibles, which was considerable.

249. **Watt's improvements in the steam engine.**—James Watt, a mathematical instrument maker in Glasgow, had to repair the model of a Newcomen's machine belonging to the physical cabinet of the University. He was struck by the enormous quantity of steam and of condensing water used by this machine. This notion became the starting-point of a long series of researches and improvements, which he pursued with admirable perseverance for fifty years, without ever being content with the success he obtained. Thus it was that Newcomen's machine, successively metamorphosed in all its parts, ultimately really became Watt's machine.

Condenser. Watt's first and principal invention was the *condenser.* This name is given to a closed vessel quite distinct from the cylinder in which the piston moves, and only connected with it by a tube provided with a stopcock. In this vessel cold water is injected, and the vapour is condensed by opening the connecting stopcock. Thus as the sides of the pump are not cooled, all the steam which enters there is utilised. Thus there was effected so great an economy of steam, and therefore of combustibles, that Watt and Boulton his partner, having taken a patent, realised great profits by only requiring, for a certain number of years, a third of the saving in the consumption of coal as compared with Newcomen's machine.

Single-acting engine. In Newcomen's engine the cylinder of which was open at the top, the steam only lifted the piston; and then, when steam was condensed, the pressure of the atmosphere brought it down again; whence the name atmospheric engine, by which it was designated. As the piston descended, air penetrated into the cylinder and cooled the sides, in consequence of which a

portion of the vapour which penetrated into the cylinder was condensed until the sides were again heated. To remove this source of loss, Watt closed the cylinder altogether, and caused the vapour to act above the piston, so as to make it descend; then by an arrangement of stopcocks, alternately opened and closed by the action of the engine itself, the steam passed simultaneously above and below the piston. This being pressed equally in opposite directions, remained in equilibrium; so that a simple counterpoise acting by means of a lever at the end of the piston rod produced an upward movement. This machine, into which air did not enter, and where the atmospheric pressure did not act, was called the *single-acting engine*, to express that the steam had a useful action on only one side of the piston.

The single-acting engine had the great disadvantage that it had no real force except when the piston was descending. It could transmit motion to pumps for emptying mines, because, for that, effort in only one direction was required; but it would not furnish a sufficiently regular motion for many industries, for cotton manufactures for instance. Hence Watt's task was not completed; and he was not long in finding another plan.

Double-acting engine. In this engine, which we shall presently describe, and which, as represented in fig. 191, the cylinder is closed both at top and at the bottom, but the steam acts alternately on the two faces of the piston; that is to say, that by a system of stopcocks, opened and closed by the engine itself, when the lower part of the cylinder communicates with the condenser, the upper part, on the contrary, is connected with the boiler, and the steam acting in all its force on the piston causes it to descend. Then when this is at the bottom of its stroke the parts change; the top of the cylinder is in connection with the condenser, and the bottom with the boiler; the piston rises again and so forth, whence results an alternating rectilinear motion which is changed into a continuous circular motion, as will be presently described (250).

Air-pump. Watt completed his engine by the addition of three pumps, which are worked by the engine, and play an important part. For the cold water of the condenser becomes rapidly heated by the heat which the steam gives up to it (240), and this water, soon reaching 100 degrees, would no longer condense the steam. Moreover the air, which is always dissolved in cold water, is liberated in the boiler, owing to the increase in temperature. Now this

air, passing both above and below the piston, would soon stop its motion. To prevent these two injurious effects, Watt applied to the machine a suction-pump, which continually withdrew from the condenser the air and water which tended to accumulate there.

Feed-pump and *cold-water-pump*. The two other pumps which Watt added are the feed-pump and the cold-water-pump. The first is a force-pump which sends into the boiler the hot water withdrawn from the condenser by the air-pump, thus producing a considerable saving in fuel. The other is a suction-pump, which raises either from a well or a river, or some other source, the cold water intended to replace that heated in the condenser, and withdrawn by the air-pump.

Besides the important parts which have thus been described, we owe to Watt the arrangement for distributing the steam alternately above and below the piston: the *regulator*, whose function, when the machine works too slowly, is to admit more steam into the cylinder, and, on the other hand, to diminish the quantity when the velocity is too great. Lastly, the *parallelogram*, which imparts to the piston rod a rectilinear motion. We may add that Watt, who had commenced life as a philosophical instrument maker, carried into the execution of these great mechanisms the same geometric rigour and the same perfection, as for the best instruments for scientific use.

250. **Description of the double-acting engine.** — We have already seen that the double-action engine is that in which the steam acts alternately above and below the piston (249). Fig. 191 represents an engine of this kind, and fig. 194 gives a section of the cylinder, of the piston, and of the distribution of steam. The entire machine is of iron. To the piston T is fixed a rod A, which slides with gentle friction in a tubulure U placed at the centre of the plate which closes the cylinder (fig. 195). As it is very important that no steam shall escape between the piston rod and this tubulure, the latter is formed of two pieces, one attached to the plate, while the other, which fits in the first, can be pressed as tightly as is desired, so as to compress the material soaked with fat which is between the two tubulures. This arrangement is called a *stuffing box*; it prevents the escape of steam without interfering with the motion of the piston.

On the two sides of the cylinder are two columns *h h*, which guide the piston rod in its upward and downward motion. The end

of the piston rod is connected with a long piece B, called the *connecting rod*, which in turn is jointed with a shorter piece M, called

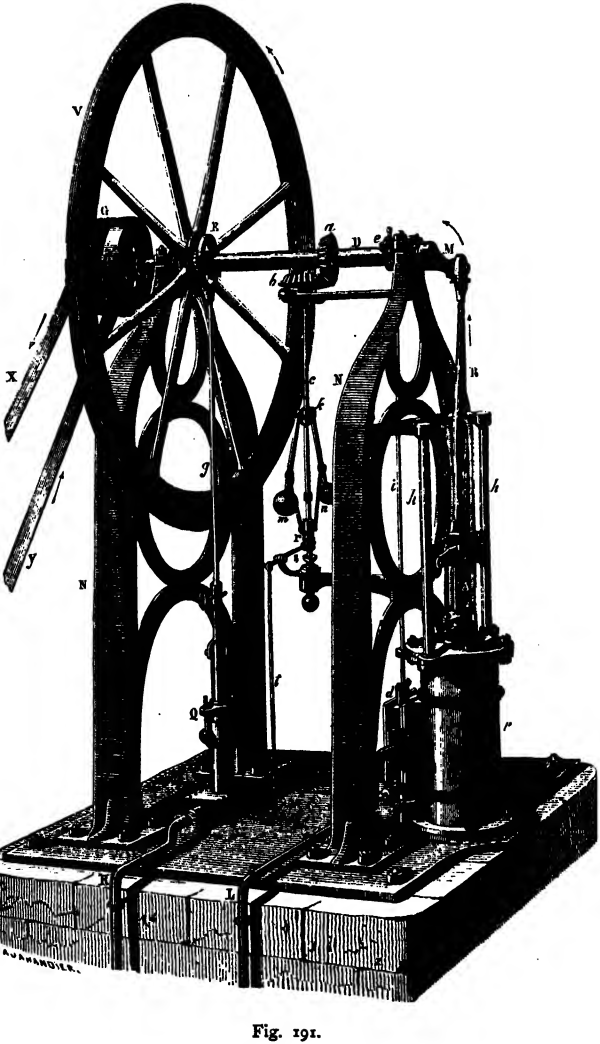

Fig. 191.

the crank, the length of which is just half that of the stroke of the piston. This is rigidly fixed to a *horizontal shaft*, D, so that it cannot move without transmitting its motion.

By means of this connecting rod and crank, the alternating rectilinear motion of the piston and of the rod is changed into a continuous circular motion. For if we look at the rod during the ascent of the piston, it acts upwards upon the crank, making it turn in the direction of the arrow. When the piston is at the top of its stroke, the motion rod and the crank are one in front of the other. As the piston descends the motion rod again acts, so as always to turn it in the same direction; and when the piston is at the bottom of the stroke, they are again vertical, but one in the prolongation of the other. Hence it follows that the axle which has made half a turn during the ascent, makes a second one during the descent, and thus a complete revolution during each double oscillation of the piston.

To transmit the motion to machinery, on the axle D is fixed a sheave on which works an *endless band* XY of leather, or gutta percha, which works on another sheave fixed to the machinery to be turned. Moved by the first sheave, this band communicates its motion to the second; in this manner the motion is transmitted to all the workshops of a large factory. On the right of the fixed sheave, G, there is a second, which is not fixed to the horizontal shaft; this is the movable sheave. Its object is to suspend all the motion in the machine without stopping the steam engine. By means of an iron fork not seen in the figure, which encloses the band, the latter may be slid from the fixed to the movable sheave. As this latter is not connected with the horizontal shaft, it does not turn with it, and does not transmit its motion to the band.

On the horizontal shaft is a large iron wheel V, called the *fly-wheel*. This wheel, which is very large, is necessary for keeping up the motion. For each turn that the piston is at the top or bottom of its stroke, there is a momentary arrest, during which the motion of the whole machine tends to stop. It is then that the flywheel, in virtue of its inertia and of its acquired velocity, moves the horizontal shaft, and thus keeps up a regular motion.

251. **Excentric. Valve-chest.**—The excentric is an arrangement by which a continuous circular motion is changed into an alternating rectilinear motion. It is very frequently used in machinery.

One of these is fitted to the horizontal shaft at E, and the other

at *e*. The former works the *feed-pump*, and the latter the *valve-chest.* The action of both is the same. Figures 192 and 193 represent it on a larger scale, in two diametrically opposite positions. It consists of a circular piece KE, fixed to the horizontal shaft, but in such a manner that the centre of rotation does not coincide with the centre of the piece; the latter being at C, the former at O. It follows from this construction that the point C constantly describes about O a circumference which is represented in the drawing by a dotted line. Hence in each half turn it passes from the position

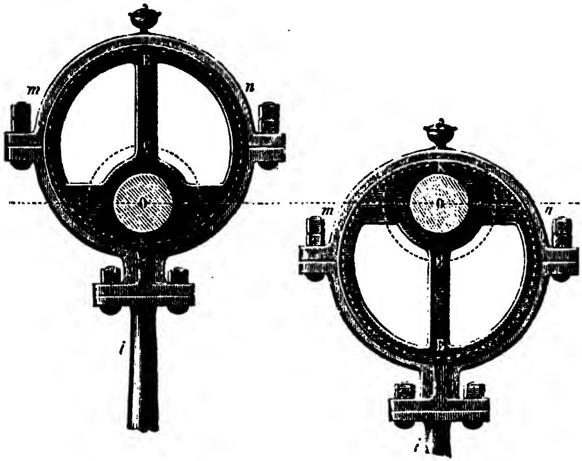

Fig. 192. Fig. 193.

represented in fig. 192 to that represented in fig. 193, and *vice versâ*. So that the point C, in turning about the point O, does really perform an up and down motion.

To use this motion the excentric is surrounded by a *collar mn*, in which it can turn freely like an axle in its box: hence, during the rotation of the horizontal shaft, the collar shares the ascending and descending motion of the point C, but not its rotatory motion. The excentric alone turns, the collar only rises and sinks. By thus transmitting its motion to a rod *i*, it works the valve-chest.

Valve-chest. We have still to describe the valve-chest, the arrangement by which steam passes alternately above and below the piston. Fig. 195 presents a vertical section of this valve-chest, and of the cylinder. The steam enters the valve-chest from the boiler

by the brass tube *x*. From the valve-chests two conduits, *a* and *b*, are connected with the cylinder, one above and the other below. If they were both open at once, the steam acting equally on the two faces of the piston, would keep it at rest. But one of these is always closed by a *slide valve*, *y*, fixed to a rod, *i*. This moves alternately, upwards and downwards, by means of an excentric, *e*, placed on the horizontal shaft. In fig. 195 the slide-valve closes the conduit *a*, and allowing the vapour to enter at *b*, above the piston, the

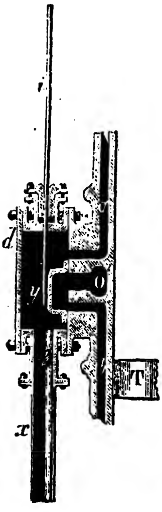

Fig. 194.

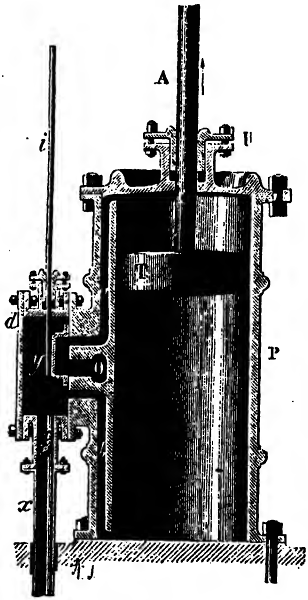

Fig. 195.

latter rises. But when it reaches the top of the stroke the excentric has passed from the position represented in fig. 192 to that in fig. 193; hence the rod, *i*, sinks, and with it the slide-valve, which then closes the conduit *b*, and allows the vapour to enter at *a* (fig. 194). The piston then sinks, and so forth at each displacement of the slide-valve.

In completing this account of the manner in which steam is distributed, it remains to explain what happens when the steam presses below the piston (fig. 195). It must not remain above, otherwise the

piston could not move. But while the steam enters below by the conduit *b*, the top of the cylinder, by means of a conduit *a*, is connected with a cavity O, from which passes a tube L. Through this tube the steam which has already acted upon the piston passes into the atmosphere, or else is condensed in a vessel filled with cold water, which has been already mentioned, *the condenser* (249). If, on the other hand, the piston sinks, the slide-valve being in the position of fig. 194, the vapour below the piston passes by the conduit, *b*, to the cavity O, and to the tube L.

252. **Regulator.**—The object of this arrangement is to regulate the quantity of steam which reaches the valve-chest, increasing it when the machine works too slowly and diminishing it when it works too rapidly. It consists of a parallelogram, K*r*, each apex of which is jointed. A toothed wheel, *a*, connected with the horizontal shaft, transmits its motion to a similar wheel, *b*, fixed to the rod *c*, which supports the parallelogram. This turns then with the rod the more rapidly the greater the velocity of the machine. But the two upper arms are provided with two solid spheres, *m* and *n*; moreover, a socket, *r*, to which are attached the two lower arms, is not fixed to the rod *c*, but can glide along it. Hence the centrifugal force (28) acting on the balls *m* and *n* makes them diverge, the parallelogram opens, and the socket rises. It transmits its motion to a lever, *s*, the front arm of which lowering presses upon a long rod, *t*. This inclining the lever, O, effects a small rotation in a valve, *v*, placed in the tube *x*, by which steam comes (fig. 195). This valve, either by stopping the tube *x*, or leaving it open, admits more or less steam.

253. **Feed-pump.**—The object of this, as its name implies, is to renew the water in the boiler in the degree in which it evaporates. In fig. 191 this pump, placed at Q, on the left of the drawing, receives its motion from an excentric by means of a long rod, and it works both as *cold-water-pump* and as *feed-pump*; as cold-water-pump, inasmuch as it withdraws water from a well by a suction-pipe placed below the engine; and as feed-pump by its then forcing water into the boiler by the pipe R.

254. **Various kinds of steam engines**—A *low pressure engine* is one in which the tension of the vapour does not much exceed an atmosphere; and a ***high pressure engine*** is one in which the pressure of the steam usually exceeds this amount considerably. Low pressure engines are mostly *condensing engines*: in other words, they generally have a condenser where the steam becomes

condensed after having acted on the piston : on the other hand, *high pressure engines* are frequently without a condenser; the locomotive is an example.

If the communication between the cylinder and boiler remains open during the whole motion of the piston, the steam retains essentially the same elastic force, and is said to act *without expansion:* but if, by a suitable arrangement of the slide-valve, the steam ceases to pass into the cylinder when the piston is at $\frac{2}{3}$ or $\frac{3}{4}$ of its course, then the vapour *expands* ; that is to say, in virtue of its elastic force, which is due to the high temperature, it still acts on the piston and causes it to finish its course. Hence a distinction is made between expanding and non-expanding engines.

The principle of expansion is not applicable to low pressure machines, for the elastic force of the vapour is inconsiderable. But for high or mean pressure engines it not only effects a great saving

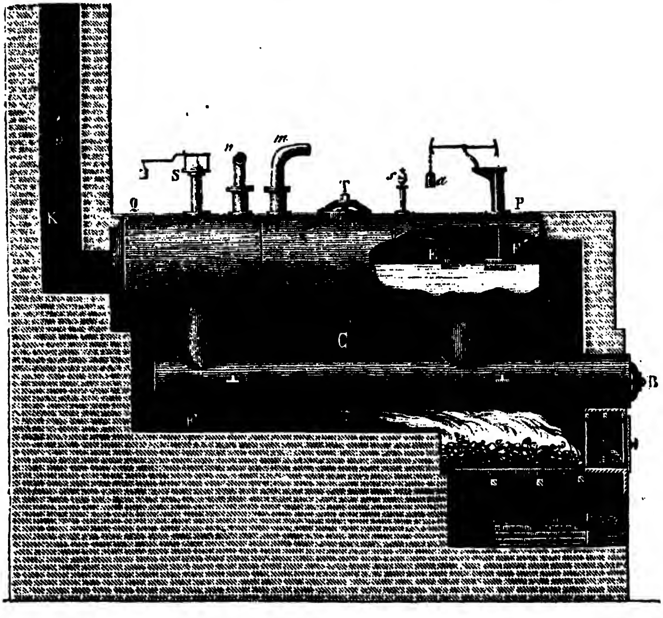

Fig. 196.

in steam, and therefore in fuel, but it regulates the motion by

diminishing the pressure the moment the acquired velocity of the piston tends to increase.

255. **Work of an engine. Horse-power.**—The work of an engine is measured by the mean pressure on the piston multiplied by the area of the piston multiplied by the length of the stroke. In England the unit of work is the *foot-pound*; that is, the work performed in raising a weight of one pound through a height of a foot. Thus, to raise a weight of 14 pounds through a height of 20 feet would require 280 foot-pounds. In France the *kilogrammeter* is used; that is, the work performed in raising a kilogramme through a metre. This unit corresponds to 7·233 foot-pounds.

The *rate of work* in machines is the amount of work performed in a given time; a second or an hour, for example. In England the rates of work are compared by means of *horse-power*, which is a conventional unit, and represents 550 foot-pounds in a second. In France a similar unit is used, called the *cheval vapeur*, which represents the work performed in raising 75 kilogrammes through one meter in a second. It is equal to about 542 foot-pounds per second.

256. **Steam-boiler.**—We have still to describe the steam boiler or arrangement in which the steam is generated, and its various accessories.

Fig. 196 gives a longitudinal and fig. 197 a transverse section of the steam boiler and its furnace. The generator consists of two wrought iron cylinders with hemispherical ends. Below are two cylinders, BB, of smaller diameter, which are called *heaters*, and which are connected with the generators by two strong tubes. The object of these heaters is to expose a greater surface to be heated. They are full of water, as also are the tubes which connect them with the boiler, which is only half full.

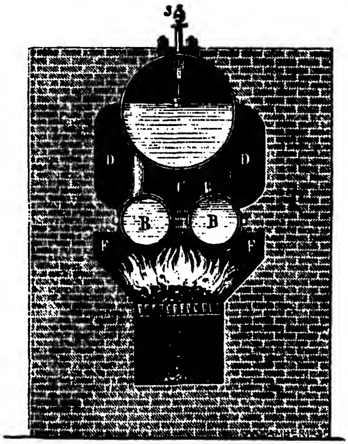

Fig. 197.

The feed-water sent by the pump, Q, reaches the boiler by a tubu-

lure, *n*, which is immersed to the bottom to prevent cold water from condensing vapour; a second tubulure, *m*, leads the vapour to the valve-chest. In the middle of the boiler is an oval hole called a *manhole*, the object of which is to allow workmen to enter the boiler when it needs repair. This hole, as well as two front ones, of the heaters are closed by what are called *autoclaves*. Here the cover instead of being on the outside is on the inside. A screw T fixed to this cover makes it press against the sides; and as the pressure of the vapour acts in the same direction, the greater the pressure the more tightly is the vessel closed.

The furnace in which the boiler is placed, is so constructed as to multiply the surface heated, and to render the combustion as complete as possible. The products of combustion pass into tall chimneys, which from their great height increase the draught and thereby promote the combustion.

257. **Float.**—This is a small apparatus, the object of which is to indicate the level of water in the boiler. It consists of a lever, at one end of which is a piece of stone, F, and at the other a counterpoise, *a*. The mass F weighs more than the counterpoise *a*; but as it is immersed in water, and thus loses part of its weight (95), it is in equilibrium, and the lever is horizontal so long as the level of water is at the desired height. But it sinks when there is too little water, and rises in the contrary direction when there is too much. Guided by these indications, the stoker can regulate the supply of water.

258. **Safety-valve.**—The pressure of steam in the boiler is measured by means of the manometer (133). But this instrument would not prevent explosions if its indications were neglected. Hence on boilers two safety-valves are placed, similar to that which Papin adopted in his digester (235). Fig. 198 represents on a larger scale one of these valves. It consists of a metal stopper closing a tubulure fixed on the boiler A. To prevent this from sinking to the sides the metal stopper is hollowed on three sides. It thus more resembles a clack-valve than an ordinary cork. On the piece rests a movable lever, *ab*, loaded with a weight. By moving this along the lever the load

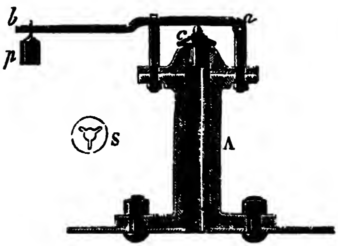

Fig. 198.

on the valve can be modified at will. For this purpose marks are placed which indicate the position of the load which corresponds to a given pressure. Thus, suppose it is desired that the pressure shall not exceed 5 atmospheres, the weight is placed at the division 5 on the lever. Then, as long as the pressure is less than 5, the safety-valve remains closed; but, if the pressure exceeds this amount, the valve opens and gives exit to the steam, thus preventing an explosion.

×259. **Safety-whistle.**—This is another safety apparatus, which indicates at a distance when the level of water in the boiler is too low. It consists of a float, F (fig. 199), supported by a lever, *ih*, which moves about the joint *c*; a counterpoise, *p*, balances the

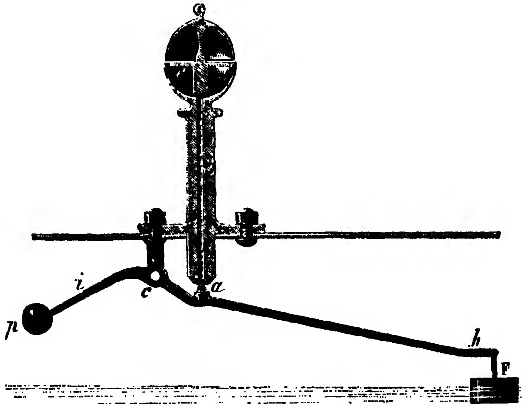

Fig. 199.

float, and a small conical stopper, *a*, fixed to the lever, closes a tubulure on the boiler. This tubulure is closed at the top by two hollow hemispheres. In the centre of the lower arc is a disc, which does not quite reach the edges. Between the two hemispheres is a circular interval through which vapour escapes when the cone *a* does not close the tubulure.

As long as the water is at the right height the float F is raised, and presses the cone against the tubulure; but if the level sinks the float sinks, and with it the cone. The steam escapes round the disc *e*, and gives a very acute sound in striking against the edges of the upper hemisphere which are bevelled. The system con-

stitutes a true organ pipe with a very short mouthpiece, and yielding, therefore, a very acute sound.

On locomotives a similar whistle enables the driver to signal at a great distance by opening a stopcock, which allows the steam to escape.

CHAPTER XI.

HYGROMETRY.

260. **Object of hygrometry.**—The object of *hygrometry* is to determine the quantity of aqueous vapour contained in a given volume of air. This quantity is very variable; but the atmosphere is never completely saturated with vapour, at any rate, in our climates. Nor is it ever completely dry; for if *hygrometric substances*, that is to say, substances with a great affinity for water, such as chloride of calcium, sulphuric acid, etc., be at any time exposed to the air, they absorb aqueous vapour.

The degree of moisture does not depend on the absolute quantity of aqueous vapour present in the air, but on the greater or less distance of the air from its point of saturation. When the air is cold, it may be moist with very little vapour, and, on the contrary, when it is warm, very dry, even with a large quantity of vapour. In summer the air usually contains more aqueous vapour than in winter, notwithstanding which it is less moist, because, the temperature being higher, the vapour is farther from its point of saturation. When a room is warmed, the quantity of moisture is not diminished, but the humidity of the air is lessened, because its point of saturation is raised. The air may thus become so dry as to be injurious to the health, and it is hence usual to place vessels of water on the stoves used for heating.

The quantity of vapcur contained in the air varies greatly with the seasons, the climates, the temperature, and various local causes. A mean degree of moisture is best suited to the animal economy. In a state of great dryness, as prevails, for instance, during the prevalence of north-east winds, the cutaneous transpiration is too abundant, the skin dries up and chaps, and general discomfort ensues. In an atmosphere which is too moist, perspiration stops, a feeling of depression and heaviness is felt. Hence it is necessary

to regulate in a suitable manner the moisture of dwelling rooms, so as to avoid these two extremes.

261. **Hygroscopes and hygrometers.**—There are two classes of instruments by which the hygrometric state of the air may be known. One class, called *hygroscopes*, simply tell whether the air is more or less moist, but give no indications as to the quantity of moisture it contains; others, called *hygrometers*, enable us to measure it with some accuracy.

All substances which absorb aqueous vapour, like common salt and many others known as *deliquescent salts*, may serve as hygroscopes. This is also the case with a great number of animal and vegetable substances, such as paper, parchment, hair, catgut, etc., which, elongating as the air becomes moist, and contracting as it becomes dry, give an indication of the greater or less quantity of vapour in the air.

Fig. 200.

A great number of instruments have been constructed which serve as *hygroscopes*. One of the commonest is that represented in fig. 200. It consists of a small figure representing a monk fixed on a support; the head is provided with a cowl of thin cardboard, movable about the point *a*, where it is attached to the end of a small piece of twisted catgut. The other end of this is fixed in a tubulure, *o*, as seen in the section. The catgut twisting as it becomes dry, and untwisting as it is moist, moves the cowl, which is carefully arranged, so that the head is covered when the atmosphere is moist, and uncovered when it is dry.

This instrument, and all others of the same class, only change slowly, and their indications are always behindhand with the state of the weather; nor are they, moreover, very exact.

262. **Hygrometric state of the air.**—By this term we do not understand the actual quantity of vapour present, but the ratio of the

quantity of vapour which the air actually contains to that which it would contain if it were saturated. Thus, if we say that the air is *three-fifths* saturated, we mean that it contains three-fifths of the vapour which it could contain in a state of saturation.

The most exact of all hygrometers are the *chemical hygrometers.* They consist essentially of an arrangement by which a given measured volume of air is passed through a series of drying tubes —that is, tubes containing some hygroscopic substance, such as chloride of calcium, or pumice saturated with sulphuric acid. These tubes, being previously weighed, are weighed again after the operation; an increase of weight is observed, which is due to the moisture absorbed by the hygroscopic substance, and this increase represents the weight of the moisture in the volume of air taken.

This method is very exact, but it is both difficult and tedious of execution.

More convenient than the above are what are called *condensation hygrometers*, in which the vapour of the atmosphere is made to condense on a body artificially cooled. When a body gradually cools in a moist atmosphere, the layer of air in immediate contact with it cools also, and a point is ultimately reached at which the vapour present is just sufficient to saturate the air: the least diminution of temperature then causes a precipitation of moisture on the body in the form of dew. When the temperature rises again, the dew disappears, and the mean of these two temperatures is taken as the *dew point.*

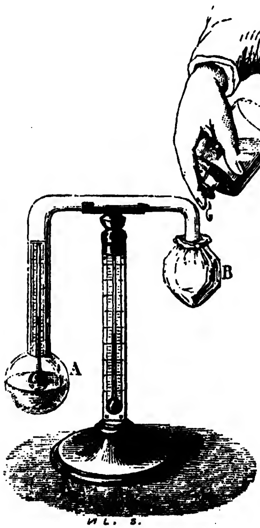

Fig. 201.

A good example of an instrument of this class is met with in *Daniell's hygrometer.* This consists of two glass bulbs at the extremities of a glass tube bent twice (fig. 201). The bulb A is two-thirds full of ether, and a very delicate thermometer dips in it; the rest of the space contains nothing but the vapour of ether, the ether

having been boiled before the bulb B was sealed. The bulb B is covered with muslin, and ether is dropped upon it. The ether in evaporating cools the bulb, and the vapour contained in it is condensed. The internal tension being thus diminished, the ether in A forms vapours which condense in the other bulb, B. In proportion as ether distils from the lower to the upper bulb, the ether in A becomes colder, and ultimately the temperature of the air in immediate contact with A sinks to that point at which its vapour is just more than sufficient to saturate it, and the excess is accordingly deposited on the outside as a ring of dew corresponding to the surface of the ether. The temperature of this point is noted by means of the thermometer in the inside. The addition of ether to the bulb B is then discontinued, the temperature of A rises, and the temperature at which the dew disappears is noted. In order to render the deposition of dew more perceptible, the bulb A is made of black glass.

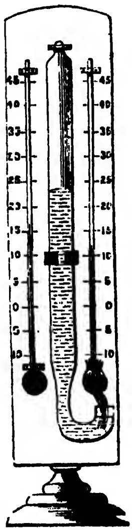

Fig. 202.

These two points having been determined, their mean is taken as that of the dew point. The temperature of the air at the time of the experiment is indicated by the thermometer on the stem. The tension f, corresponding to the temperature of the dew point, is then found in the table of tensions (236). This tension is exactly that of the vapour present in the air at the time of the experiment. The tension, F of vapour saturated at the temperature of the atmosphere is found by means of the same table; the quotient obtained by dividing f by F, represents the hygrometric state of the air. For instance, the temperature of the air being 15°, suppose the dew point is 5°. From the table the corresponding tensions are $f = 6{\cdot}534$ millimeters, and $F = 12{\cdot}699$ millimeters, which gives $0{\cdot}514$ for the ratio of f to F, or the hygrometric state.

A very convenient form of hygrometer, and one whose use is gradually extending, is that known as the *psychrometer* or *wet bulb hygrometer*, which is based on the principle that a moist body evaporates in the air more rapidly in proportion as the air is drier; and, in consequence of this evaporation, the temperature of the air sinks. The application of this principle to this purpose was first suggested by Leslie. The form usually adopted in this country

is due to Mason. It consists of two delicate thermometers placed on a wooden stand (fig. 202). One of the bulbs is covered with muslin, and is kept continually moist by being connected with a reservoir of water by means of a string. Unless the air is saturated with moisture the wet bulb thermometer always indicates a lower temperature than the other, and the difference between the indications of the two thermometers is greater in proportion as the air can take up more moisture.

According to Glaisher the temperature of the dew point may be obtained by multiplying the difference between the temperatures of the wet and dry bulb by a constant depending on the temperature of the air at the time of observation, and subtracting the product thus obtained from this last-named temperature. The following are the numbers:

Dry bulb temperature F.°	Factor	Dry bulb temperature F.°	Factor
Below 24°	8·5	34 to 35°	2·6
24 to 25	7·3	35—40	2·5
25—26	6·4	40—45	2·3
26—27	6·1	45—50	2·1
27—28	5·9	50—55	2·0
28—29	5·7	55—60	1·8
29—30	5·0	60—65	1·8
30—31	4·6	65—70	1·7
31—32	3·6	70—75	1·5
32—33	3·1	75—80	1·3
33—34	2·8	80—85	1·0

These are often known as *Glaisher's factors.*

CHAPTER XII.

METEOROLOGICAL PHENOMENA WHICH DEPEND UPON HEAT.

263. **Meteorology.**—Meteorology is that part of physics which is concerned with the phenomena which occur in the atmosphere; such, for instance, as variations in the temperature of the air, wind, rains, storms, electrical phenomena, etc. Though of quite recent origin, this science is an important application of the physical

sciences, and furnishes useful indications to navigation, agriculture, and hygiene.

264. **Mean temperature.**—The *mean daily temperature*, or simply *temperature*, is that obtained by adding together 24 hourly observations, and dividing by 24. A very close approximation to the mean temperature is obtained by taking the mean of the maxima and minima temperatures of the day and of the night, which are determined by means of the maximum and minimum thermometers (194). These ought to be protected from the solar rays, raised above the ground, and far from all objects which might influence them by their radiation. The lowest daily temperature is at 4 A.M., and the highest at 2 P.M.

The *temperature of a month* is the mean of those of 30 days, and the *temperature of the year* is the mean of those of 12 months. The highest mean monthly temperature is in July, and the lowest in January. Finally, the temperature of a place is the mean of its annual temperature, for a great series of years. The mean temperature of London is 8·28° C., or 46·9° F. The temperatures in all cases are those of the air and not those of the ground.

265. **Causes which modify the temperature of the air.**—The principal causes which modify the temperature of the air are the latitude of a place, its height—that is, its distance above the sea—the direction of the winds, and the proximity of seas.

Influence of the latitude. The temperature of the air and of the ground diminishes from the equator towards the poles. This is due to the fact, that the sun's rays, which are perpendicular at the equator, are more and more inclined as we come near the poles. Now we have seen that the greater the inclination under which the rays of heat fall upon a body, the less is the body heated; hence the heat absorbed decreases from the equator to the poles, for the rays are then more oblique. Yet, as in summer, the days are longer as we get nearer the north, the loss due to the increasing obliquity of the sun is partially compensated by the sun remaining longer above the horizon. Under the equator, where the length of the days is constant, the temperature is almost invariable; in the latitude of London, and in more northerly countries, where the days are very unequal, the temperature varies greatly; but in summer it sometimes rises almost as high as under the equator. The lowering of the temperature produced by the latitude is small; thus in a latitude of 115 miles north of ours, the temperature is only 1° C. lower.

Influence of altitude. The height of a place has a much more considerable influence on the temperature than its latitude. In the temperate zone a diminution of 1° C. corresponds in the mean to an ascent of 180 yards.

The cooling on ascending in the atmosphere has been observed in balloon ascents, and a proof of it is seen in the perpetual snows which cover the highest mountains, even under the torrid zones. The height at which perpetual snow is met with differs in different places. On the Andes it commences at a height of 14,760 feet, and on the Alps at 8,880 feet.

Direction of winds. As winds share the temperature of the countries which they have traversed, their direction exercises great influence on the air in any place. In our climate the hottest winds are the south, then come the south-east, the south-west, the west, the east, the north-west, north, and, lastly, the north-east, which is the coldest. The character of the wind changes with the seasons; the east wind, which is cold in winter, is hot in summer.

Proximity of the seas. The neighbourhood of the sea tends to render the temperature of the air uniform, by heating it in winter, and cooling it in summer. The average temperature of the sea in equatorial and polar countries is always higher than that of the atmosphere. With reference to the uniformity of the temperature, it has been found that in temperate regions, that is, from 25° to 50° of latitude, the difference between the maximum and minimum temperature of a day does not exceed, on the sea, 2° to 3°; while upon the continent this amounts to 12° to 15°. In islands the uniformity of temperature is very perceptible, even during the greatest heats. In continents, on the contrary, the winters for the same latitudes become colder, and the difference between the temperature of summer and winter becomes greater.

266. **Gulf stream.**—A similar influence to that of the winds is exerted by currents of warm water. To one of these, the Gulf stream, the mildness of the climate in the north-west of Europe is mainly due. This great body of water, taking its origin in equatorial regions, flows through the Gulf of Mexico, from whence it derives its name; passing by the southern shores of North America it makes its way in a north-westerly direction across the Atlantic, and finally washes the coast of Ireland and the north-west of Europe generally. Its temperature in the Gulf is about 28° C.; and generally it is a little more than 5° C. higher than the rest of the ocean on which it floats, owing to its lower specific gravity.

To its influence is due the milder climate of west Europe as compared with that of the opposite coast of America; thus the river Hudson, in the latitude of Rome, is frozen over three months in the year. It also causes the polar regions to be separated from the coasts of Europe by a girdle of open sea; and thus the harbour of Hammerfest is open the year round. Besides its influence in thus moderating climate the Gulf stream is an important help to navigators.

267. **Isothermal lines.**—When on a map all the points whose temperature is known to be the same are joined, curves are obtained which Humboldt first noticed, and which he called *isothermal lines.* If the temperature of a place only varied with the obliquity of the sun's rays, that is, with the latitude, isothermal lines would all be parallel to the equator; but as the temperature is influenced by many local causes, especially by the height, the isothermal lines are always more or less curved. On the sea, however, they are almost parallel. A distinction is made between *isothermal lines*, *isotheral lines*, and *isochimenal lines*, where the mean *general*, the *mean summer*, and the *mean winter* temperatures are respectively constant. An *isothermal zone* is the space comprised between two isothermal lines. Kupffer also distinguishes *isogeothermic lines*, where the mean temperature of the soil is constant.

268. **Climate.**—By the *climate* of a place is understood the whole of the meteorological conditions to which a place is subjected; its mean annual temperature, summer and winter temperatures, and by the extremes within which these are comprised. Some writers distinguish seven classes of climates, according to their mean annual temperature, a *hot climate* from 30° to 25° C.; a *warm climate* from 25° to 20° C.; a *mild climate* from 20° to 15° C.; a *temperate climate* from 15° to 10° C.; a *cold climate* from 10° to 5° C.; a *very cold climate* from 5° to zero; and an *arctic climate* where the temperature is below zero.

Those climates, again, are classed as *constant climates*, where the difference between the mean and summer and winter temperature does not exceed 6° to 8°; *variable climates*, where the difference amounts to from 16° to 20°; and *extreme climates*, where the difference is greater than 30°. The climates of Paris and London are variable; those of Pekin and New York are extreme. Island climates are generally little variable, as the temperature of the sea is constant; and hence the distinction between land and sea climates. *Marine climates* are characterised by the fact, that

the difference between the temperature of summer and winter is always less than in the case of continental climates. But the temperature is by no means the only character which influences climates; there are, in addition, the humidity of the air, the quantity and frequency of the rains, the number of storms, the direction and intensity of the winds, and the nature of the soil.

FOG. RAIN. DEW.

269. **Fogs and mists.**—When aqueous vapours, rising from a vessel of boiling water, diffuse in the colder air, they are condensed; a sort of cloud is formed which consists of a number of small hollow vesicles of water, which remain suspended in the air. These are usually spoken of as vapours, yet they are not so, at any rate not in the physical sense of the word; for they are partially condensed vapours.

When this condensation of aqueous vapours is not occasioned by contact with cold solid bodies, but takes place throughout large spaces of the atmosphere, they constitute *fogs* or *mists*, which, in fact, are nothing more than the appearance seen over a vessel of hot water.

A chief cause of fogs consists in the moist soil being at a higher temperature than the air. The vapours which then ascend condense and become visible. In all cases, however, the air must have reached its point of saturation before condensation takes place. Fogs may also be produced when a current of hot and moist air passes over a river at a lower temperature than its own, for then the air being cooled, as soon as it is saturated, the excess of vapour present is condensed.

The distinction between mists and fogs is one of degree rather than of kind. A fog is a very thick mist.

270. **Clouds.**—*Clouds* are masses of vapour, condensed into little drops or vesicles of extreme minuteness, like fogs; from which they only differ in occupying the higher regions of the atmosphere; they always result from the condensation of vapours which rise from the earth or the sea. According to their appearance, they have been divided by Howard into four principal kinds: the *nimbus*, the *stratus*, the *cumulus*, and the *cirrus*. These four kinds are represented in fig. 203, and are designated respectively by one, two, three, and four birds on the wing.

The *cirrus* consist of small whitish clouds, which have a fibrous

or wispy appearance, and occupy the highest regions of the atmosphere. The name of *mares' tails*, by which they are generally known, well describes their appearance. From the low temperature of the spaces which they occupy, it is more than probable that cirrus clouds consist of frozen particles; and hence it is that haloes, coronæ, and other optical appearances, produced by refraction and reflection from ice crystals, appear almost always in these clouds and their derivatives. Their appearance often precedes a change of weather.

The *cumulus* are rounded spherical forms which look like mountains piled one on the other. They are more frequent in summer than in winter, and, after being formed in the morning, they generally disappear towards evening. If, on the contrary, they become more numerous, and especially if surmounted by cirrus clouds, rain or storms may be expected.

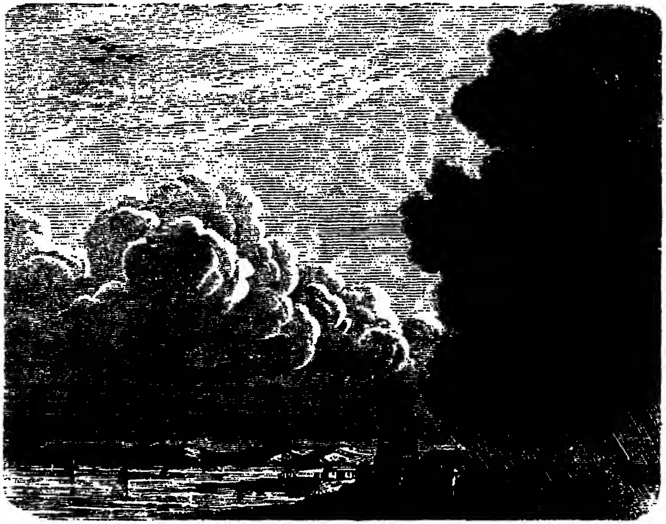

Fig. 203.

Stratus clouds consist of very large and continuous horizontal sheets, which chiefly form at sunset, and disappear at sunrise.

They are frequent in autumn and unusual in spring time, and are lower than the preceding.

The *nimbus*, or rain clouds, which are sometimes classed as one of the fundamental varieties, are properly a combination of the three preceding kinds. They affect no particular form, and are solely distinguished by a uniform grey tint, and by fringed edges. They are indicated on the right of the figure by the presence of one bird.

The fundamental forms pass into one another in the most varied manner; Howard has classed these traditional forms as *cirro-cumulus*, *cirro-stratus*, and *cumulo-stratus*, and it is often very difficult to tell, from the appearance of a cloud, which type it most resembles. The cirro-cumulus is most characteristically known as a 'mackerel sky;' it consists of small roundish masses, disposed with more or less irregularity and connection. It is frequent in summer, and attendant on warm and dry weather. *Cirro-stratus* appears to result from the subsidence of the fibres of cirrus to a horizontal position, at the same time approaching laterally. The form and relative position when seen in the distance frequently give the idea of shoals of fish. The tendency of *cumulo-stratus* is to spread, settle down into the *nimbus*, and finally fall as rain.

The height of clouds varies greatly; in the mean it is from 1,300 to 1,500 yards in winter, and from 3,300 to 4,400 yards in summer. But they often exist at greater heights; Gay-Lussac, in his balloon ascent, at a height of 7,650 yards, observed cirrus-clouds above him, which appeared still to be at a considerable height. In Ethiopia M. d'Abbadie observed storm-clouds whose height was only 230 yards above the ground.

In order to explain the suspension of clouds in the atmosphere, Halley first proposed the hypothesis of *vesicular vapours.* He supposed that clouds are formed of an infinity of extremely minute vesicles, hollow, like soap bubbles filled with air, which is hotter than the surrounding air; so that these vesicles float in the air like so many small balloons. This theory has at present many opponents, who assume that clouds and fogs consist of extremely minute droplets of water, which are retained in the atmosphere by the ascensional force of currents of hot air, just as light powders are raised by the wind. Ordinarily, clouds do not appear to descend, but this absence of downward motion is only apparent. In fact, clouds do usually fall slowly, but then the lower part is continually

dissipated on coming in contact with the lower and more heated layers; at the same time the upper part is always increasing from the condensation of new vapours, so that from these two actions clouds appear to retain the same height.

271. **Formation of clouds.**—Many causes may concur in the formation of clouds. I. The low temperature of the higher regions of the atmosphere. For owing to the solar radiation, vapours are constantly disengaged from the earth and from the waters, which from their elastic force and lower density rise in the atmosphere; meeting there continually colder and colder layers of air, they sink to the point of saturation, and then condensing in infinitely small droplets, they give rise to clouds.

II. The hot and moist currents of air rising during the day undergo a gradually feebler pressure, and thus is produced an expansion which is a source of intense cold, and produces a condensation of vapour. Hence it is that high mountains, stopping the aerial currents, and forcing them to rise, are an abundant source of rain.

III. A hot, moist current of air mixing with a colder current, undergoes a cooling, which brings about a condensation of the vapour. Thus the hot and moist winds of the south and south-west, mixing with the colder air of our latitude, give rain. The winds of the north and north-east tend also, in mixing with our atmosphere, to condense the vapours; but as these winds, owing to their low temperature, are very dry, the mixture rarely attains saturation, and generally gives no rain.

272. **Rain.**—When by the constant condensation of aqueous vapour the individual vapour vesicles become larger and heavier, and when finally individual vesicles unite, they form regular drops, which fall as *rain*. The quantity of rain which falls annually in any given place, or the annual rainfall, is measured by means of a *rain gauge* or *pluviometer*.

Many local circumstances may affect the quantity of rain which falls in different countries; but, other things being equal, most rain falls in hot climates, for there the vaporisation is most abundant. The rain-fall decreases, in fact, from the equator to the poles. At London it is 23·5 inches; at Bordeaux it is 25·8; at Madeira it is 27·7; at Havannah it is 91·2; and at St. Domingo it is 107·6. The quantity varies with the seasons; in Paris, in winter, it is 4·2 inches; in spring 6·9; in summer 6·3; and in autumn 4·8 inches.

An inch of rain on a square yard of surface expresses a fall of 46·74 pounds, or 4·67 gallons. On an acre it corresponds to 22,622 gallons, or 100·9935 tons. 100 tons per inch per acre is a ready way of remembering this.

273. **Dew. Hoar frost.**—*Dew* is merely aqueous vapour which has condensed on bodies during the night in the form of minute globules. It is occasioned by the chilling which bodies near the surface of the earth experience in consequence of nocturnal radiation. Their temperature having then sunk several degrees below that of the air, it frequently happens, especially in hot seasons, that this temperature is below that at which the atmosphere is saturated. The layer of air which is immediately in contact with the chilled bodies, and which virtually has the same temperature, then deposits a portion of the vapour which it contains: just as when a bottle of cold water is brought into a warm room, it becomes covered with moisture, owing to the condensation of aqueous vapour upon it.

According to this theory, which was first propounded by Dr. Wells, all causes which promote the cooling of bodies increase the quantity of dew. These causes are the emissive power of bodies, the state of the sky, and the agitation of the air. Bodies which have a great radiating power more readily become cool, and therefore ought to condense more vapour. In fact, there is generally no deposit of dew on metals, whose radiating power is very small, especially when they are polished; while the ground, sand, glass, and plants, which have a great radiating power, become abundantly covered with dew. On some plants, for instance, not merely are droplets of dew formed, but regular layers of water.

The state of the sky also exercises a great influence on the formation of dew. If the sky is cloudless, the planetary spaces send to the earth an inappreciable quantity of heat, while the earth radiates very considerably, and therefore becoming very much chilled, there is an abundant deposit of dew. But if there are clouds, as their temperature is far higher than that of the planetary spaces, they radiate in turn towards the earth, and as bodies on the surface of the earth only experience a feeble chilling, no deposit of dew takes place.

Wind also influences the quantity of vapour deposited. If it is feeble, it increases it, inasmuch as it renews the air; if it is strong, it diminishes it, as it heats the bodies by contact, and thus does not allow the air time to become cooled. Finally, the deposit of dew is

more abundant according as the air is moister, for then it is nearer its point of saturation.

Hoar frost and *rime* are nothing more than dew which has been deposited on bodies cooled below zero, and has therefore become frozen. The flocculent form which the small crystals present, of which rime is formed, shows that the vapours solidify directly, without passing through the liquid state. Hoar frost, like dew, is formed on bodies which radiate most, such as the stalks and leaves of vegetables, and is chiefly deposited on the parts turned towards the sky.

274. **Snow. Sleet.** *Snow* is water solidified in stellate crystals, variously modified, and floating in the atmosphere. These crystals arise from the congelation of the minute vesicles which constitute the clouds, when the temperature of the latter is below zero. They

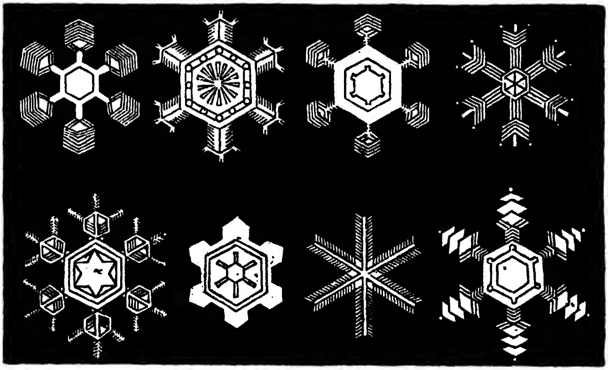

Fig. 204.

are more regular when formed in a calm atmosphere. Their form may be investigated by collecting them on a black surface, and viewing them through a strong lens. The regularity, and at the same time variety, of their forms are truly beautiful. Fig. 204 shows some of the forms as seen through a microscope.

It snows most in countries near the poles, or which are high above the sea level. Towards the poles, the earth is constantly covered with snow; the same is the case on high mountains, where there are perpetual snows even in equatorial countries.

Sleet is also solidified water, and consists of small icy needles

pressed together in a confused manner. Its formation is ascribed to the sudden congelation of the minute globules of the clouds in an agitated atmosphere.

275. **Hail.**—*Hail* is a mass of compact globules of ice of different sizes, which fall in the atmosphere. In our climates hail falls principally during spring and summer, and at the hottest times of the day: it rarely falls at night. The fall of hail is always preceded by a peculiar noise.

Hail is generally the precursor of storms, it rarely accompanies them, and follows them more rarely still. Hail falls from the size of small peas to that of an egg or an orange. The formation of hailstones has never been altogether satisfactorily accounted for; nor more especially their great size. On Volta's theory the hailstones are successively attracted by two clouds charged with opposite electricities; but if the hailstones were thus attracted, it is much more probable that the two clouds would be mutually attracted, and would unite.

ON WINDS IN GENERAL.

276. **Direction and velocity of winds.**—*Winds* are currents moving in the atmosphere with variable directions and velocities. There are eight principal directions in which they blow: *north*, *north-east*, *east*, *south-east*, *south*, *south-west*, *west*, and *north-west*. Mariners further divide each of the distances between these eight directions into four others, making in all 32 directions, which are called *points* or *rhumbs*. A figure of these 32 rhumbs on a circle, in the form of a star, is known as the *mariner's card*.

The direction of the wind is determined by means of vanes, and its velocity by means of the *anemometer*. There are several forms of this instrument; the most usual consists of a small vane with fans, which the wind turns; the velocity is deduced from the number of turns made in a given time, which is measured by means of an endless screw and wheelwork. In our climate the mean velocity is from 18 to 20 feet in a second. With a velocity of 6 or 7 feet, the wind is moderate; with 30 or 35 feet, it is fresh; with 60 or 70 feet, it is strong; with a velocity of 85 to 90 feet, it is a tempest, and from 90 to 120 it is a hurricane.

277. **Causes of winds.**—Winds are produced by the disturbance of the equilibrium in some part of the atmosphere, a disturbance

always resulting from a difference in temperature between adjacent countries. Thus, if the temperature of a certain extent of ground becomes higher, the air in contact with it becomes heated, it expands, and rises towards the higher regions of the atmosphere; whence it flows, producing winds which blow from hot to cold countries. But at the same time the equilibrium is destroyed at the surface of the earth, for the barometric pressure on the colder adjacent parts is greater than on that which has been heated, and hence a current will be produced with a velocity dependent on the difference between these pressures; thus two distinct winds will be produced, an upper one setting *outwards* from the heated region, and a lower one setting *inwards* towards it.

278. **Regular, periodical, and variable winds.**—According to the more or less constant directions in which winds blow, they may be classed as regular, periodical, and variable winds.

i. *Regular winds* are those which blow all the year through in a virtually constant direction. These winds, which are also known as the *trade winds*, are uninterruptedly observed far from the land in equatorial regions, blowing from the north-east to the south-west in the northern hemisphere, and from the south-east to the north-west in the southern hemisphere. They prevail on the two sides of the equator as far as 30° of latitude, and they blow in the same direction as the apparent motion of the sun, that is, from east to west.

The air above the equator being gradually heated, rises as the sun passes round from east to west, and its place is supplied by the colder air from the north or south. The direction of the wind, however, is modified by this fact; that the velocity which this colder air has derived from the rotation of the earth, namely, the velocity of the surface of the earth at the point from which it started, is less than the velocity of the surface of the earth at the point at which it has now arrived; hence the currents acquire, in reference to the equator, the constant direction which constitutes the trade winds.

ii. *Periodical winds* are those which blow regularly in the same direction at the same seasons, and at the same hours of the day; the monsoon, simoom, and the land and sea breeze are examples of this class. The name *monsoon* is given to winds which blow for six months in one direction, and for six months in another. They are principally observed in the Red Sea and in the Arabian

Gulf, in the Bay of Bengal and in the Chinese Sea. These winds blow towards the continents in summer, and in a contrary direction in winter. The *simoom* is a hot wind which blows over the deserts of Asia and Africa, and which is characterised by its high temperature and by the sands which it raises in the atmosphere and carries with it. During the prevalence of this wind the air is darkened, the skin feels dry, the respiration is accelerated, and a burning thirst is experienced.

This wind is known under the name of *sirocco* in Italy and Algiers, where it blows from the great desert of Sahara. During its prevalence people remain at home, the windows and doors being carefully closed. In Egypt, where it prevails from the end of April to June, it is called *kamsin*, from a word signifying *fifty*; for it lasts ordinarily 50 days; 25 before the spring equinox, and 25 after. When caravans are surprised by this wind, men cover their faces with thick clothes, and camels turn their backs to the torment. The natives of Africa, in order to protect themselves from the effects of the too rapid perspiration occasioned by this wind, cover themselves with fatty substances.

The *land* and *sea breeze* is a wind which blows on the sea coast during the day from the sea towards the land, and during the night from the land to the sea. For during the day the land becomes more heated than the sea, in consequence of its lower specific heat and greater conductivity, and hence as the superincumbent air becomes more heated than that upon the sea, it ascends and is replaced by a current of colder and denser air flowing from the sea towards the land. During the night the land cools more rapidly than the sea, and hence the same phenomenon is produced in a contrary direction. The sea breeze commences after sunrise, increases to three o'clock in the afternoon, decreases towards evening, and is changed into a land breeze after sunset. These winds are only perceived at a slight distance from the shores. They are regular in the tropics, but less so in our climates; and traces of them are seen as far as the coasts of Greenland. The proximity of mountains also gives rise to periodical daily breezes.

iii. *Variable winds* are those which blow sometimes in one direction and sometimes in another, alternately, without being subject to any law. In mean latitudes the direction of the winds is very variable; towards the poles this irregularity increases, and under the arctic zone the winds frequently blow from several points

of the horizon at once. On the other hand, in approaching the torrid zone, they become more regular. The south-west wind prevails in the north of France, in England, and in Germany; in the south of France the direction inclines towards the north, and in Spain and Italy the north wind predominates.

279. **Law of the rotation of winds.**—Spite of the great irregularity which characterises the direction of the winds in our latitude, it has been ascertained that the wind has a preponderating tendency to veer round according to the sun's motion; that is, to pass from north, through north-east, east, south-east to south, and so on round in the same direction from west to north; that it often makes a complete circuit in that direction, or more than one in succession, occupying many days in doing so, but that it rarely veers, and very rarely or never makes a complete circuit in the opposite direction.

For a station in south latitude a contrary law of rotation prevails.

This law, though more or less suspected for a long time, was first formally enunciated and explained by Dove, and is known as *Dove's law of rotation of winds.*

CHAPTER XIII.

SOURCES OF HEAT AND COLD.

280. **Different sources of heat.**—The following different sources of heat may be distinguished: i. the *mechanical sources*, comprising friction, percussion, and pressure; ii. the *physical sources*—that is, solar radiation, terrestrial heat, the molecular actions, the changes of condition, and electricity; iii. the *chemical sources*, or molecular combinations, and more especially combustion.

MECHANICAL SOURCES.

281. **Heat due to friction.**—The friction of two bodies, one against the other, produces heat, which is greater the greater the pressure and the more rapid the motion. For example, the axles of carriage wheels, by their friction against the boxes, often become so strongly heated as to take fire. By rubbing together two pieces

of ice in a vacuum below zero, Sir H. Davy partially melted them. In boring a brass cannon Rumford found that the heat developed in the course of $2\frac{1}{2}$ hours was sufficient to raise $26\frac{1}{2}$ pounds of water from zero to the boiling point.

282. **Heat due to pressure and percussion.**—If a body be so compressed that its density is increased, its temperature rises according as the volume diminishes. In solids and liquids, which are but little compressible, the disengagement of heat is not great; though Joule has verified it in the case of water and of oil, which were exposed to pressures of 15 to 25 atmospheres. Similarly, when weights are laid on metallic pillars, heat is evolved, and absorbed when they are removed.

The production of heat by the compression of gases is easily shown by means of the *pneumatic syringe* (fig. 205). This consists

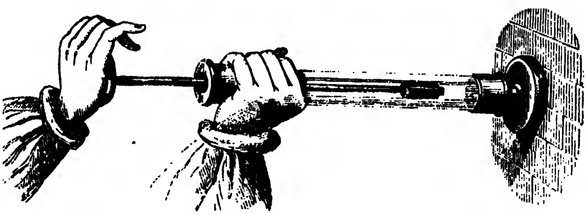

Fig. 205.

of a glass tube with thick sides, closed hermetically by a leathern piston. At the bottom of this, there is a cavity in which a small piece of tinder is placed. The tube being full of air the piston is suddenly plunged downwards, the air thus compressed disengages so much heat as to ignite the tinder, which is seen to burn when the piston is rapidly withdrawn. The inflammation of the tinder in this experiment indicates a temperature of at least 300°. At the moment of compression a bright flash is observed, which was originally attributed to the high temperature of the air; but it is simply due to the combustion of the oil which greases the piston.

Percussion is also a source of heat, as is observed in the sparks which are thrown off by horses in trotting over a hard pavement. In firing shot at an iron target, a sheet of flame is frequently seen at the moment of impact; and Mr. Whitworth has used iron shells which are exploded by the concussion on striking an iron target. A small piece of iron hammered on the anvil becomes very hot. The heat is not simply due to an approximation of the molecules,

that is, to an increase in density, but arises from a vibratory motion imparted to them; for lead, which does not become denser by being hammered, nevertheless becomes heated.

PHYSICAL SOURCES.

283. **Solar radiation.**—The most intense of all sources of heat is the sun. The cause of its heat is unknown; some have considered it to be an ignited mass experiencing immense eruptions, while others have regarded it as composed of layers acting chemically on each other like the couples of a voltaic battery, and giving rise to electrical currents, which produce light and solar heat. On both hypotheses the incandescence of the sun would have a limit.

Different attempts have been made to determine the quantity of heat annually emitted by the sun. M. Pouillet, by means of an apparatus which he calls a *pyrheliometer*, has calculated that if the total quantity of heat which the earth receives from the sun in the course of a year were employed to melt ice, it would be capable of melting a layer of ice all round the earth of 35 yards in thickness. But from the surface which the earth exposes to the solar radiation, and from the distance which separates the earth from the sun, the quantity of heat which the earth receives can only be $\frac{1}{2,381,000,000}$ of the heat emitted by the sun.

Faraday has calculated that the average amount of heat radiated in a day on each acre of ground in the latitude of London is equal to that which would be produced by the combustion of sixty sacks of coal.

284. **Terrestrial heat.**—Our globe possesses a heat peculiar to it, which is called the *terrestrial heat*. The temperature of the earth gradually sinks from the surface to a certain depth, at which it remains constant in all seasons. It is hence concluded that the solar heat does not penetrate below a certain internal layer, which is called the *layer of constant temperature*: its depth below the earth's external surface varies, of course, in different parts of the globe; at Paris it is about 30 yards, and the temperature is constant at 11·8° C.

Below the layer of constant temperature, the temperature is observed to increase, on the average 1° C. for every 90 feet. This increase has been verified in mines and artesian wells. According to this, at a depth of 3,000 yards, the temperature of a corresponding

layer would be 100°, and at a depth of 20 to 30 miles there would be a temperature sufficient to melt all substances which exist on the surface. Hot springs and volcanoes confirm the existence of this central heat.

The heat produced by the changes of condition has been already treated of in the articles *solidification* and *liquefaction*; the heat produced by electrical action will be discussed under the head of ELECTRICITY.

CHEMICAL SOURCES.

285. **Chemical combinations. Combustion.**—Whenever two bodies unite in virtue of their reciprocal affinity this operation is known as the act of *chemical combination.* Chemical combinations are usually accompanied by a certain elevation of temperature. When these combinations take place slowly, as when iron oxidises in the air, and produces rust, the heat produced is imperceptible; but if they take place rapidly, the disengagement of heat is very intense. The same quantity of heat is produced in both cases, but when evolved slowly it is dissipated as fast as formed.

Combustion is chemical combination attended with the evolution of light and heat. In the ordinary combustion in lamps, fires, candles, the carbon and hydrogen of the coal or of the oil, etc., combine with the oxygen of the air, giving rise to aqueous vapour, gases, and other volatile products which are given off as smoke. The old expression that *fire destroys everything* is incorrect. It destroys nothing, it simply puts certain elements at liberty to unite with others; it decomposes but at the same time produces. A body in being burned is transformed, but its substance is not destroyed.

Many combustibles burn with flame. A *flame* is a gas or vapour raised to a high temperature by combustion. Its illuminating power varies with the nature of the product formed. The presence of a solid body in the flame increases the illuminating power. The flames of hydrogen, carbonic oxide, and alcohol are pale, because they only contain gaseous products of combustion. But the flames of candles, lamps, coal gas, have a high illuminating power. They owe this to the fact, that the high temperature produced decomposes certain of the gases with the production of carbon, which, not being perfectly burned, becomes incandescent in the flame. Coal gas, when burnt in an arrangement by which it obtains an adequate supply of air, is almost entirely devoid of luminosity. A non-luminous flame may be made luminous by placing it in platinum wire,

or asbestos. The temperature of a flame does not depend on its illuminating power. A hydrogen flame, which is the palest of all flames, gives the greatest heat.

SOURCES OF COLD.

286. **Various sources of cold.**—Besides the cold caused by the passage of a body from the solid to the liquid state, of which we have already spoken, cold is produced by the expansion of gases, by radiation in general, and more especially by nocturnal radiation.

287. **Cold produced by the expansion of gases.**—We have seen, that when a gas is compressed, the temperature rises. The reverse of this is also the case: when a gas is rarefied a reduction of temperature ensues, because a quantity of sensible heat disappears when the gas becomes increased to a larger volume. This may be shown by placing a delicate Breguet's thermometer under the receiver of an air-pump, and exhausting; at each stroke of the piston the needle moves in the direction of zero, and regains its original temperature when air is admitted. Kirk has invented a machine for the manufacture of ice, which depends on this property. The heat developed by the compression of air is removed by a current of cold water; the vessel containing the compressed air being placed in brine, the air is allowed to expand; in so doing it cools the brine so considerably as to freeze water contained in vessels placed in the brine. It is stated that by this means a ton of coals (used in working a steam engine by which the compression is effected) can produce a ton of ice.

288. **Cold produced by nocturnal radiation.**—During the day, the ground receives from the sun more heat than radiates into space, and the temperature rises. The reverse is the case during night. The heat which the earth loses by radiation is no longer compensated for, and consequently a fall of temperature takes place, which is greater according as the sky is clearer, for clouds send towards the earth rays of greater intensity than those which come from the celestial spaces. In some winters it has been found that rivers have not frozen, the sky having been cloudy, although the thermometer has been for several days below $-4°$; while in other less severe winters the rivers freeze when the sky is clear. The emissive power exercises a great influence on the cold produced by radiation; the greater it is the greater is the cold.

In Bengal, the nocturnal cooling is used in manufacturing ice.

Large flat vessels containing water are placed on non-conducting substances, such as straw or dry leaves. In consequence of the radiation the water freezes, even when the temperature of the air is 10° C. The same method can be applied in all cases with a clear sky.

It is said that the Peruvians, in order to preserve the shoots of young plants from freezing, light great fires in their neighbourhood, the smoke of which producing an artificial cloud, hinders the cooling produced by radiation.

Country people are in the habit of saying, that it freezes more when the moon appears than when it is hidden by clouds. They are right in this; but the freezing is not, as they think, due to the influence of the moon. It is owing to the absence of clouds.

BOOK VI.

ON LIGHT.

CHAPTER I.

TRANSMISSION, VELOCITY, AND INTENSITY OF LIGHT.

289. **Theories of light.**—*Light* is the agent which, by its action on the retina, excites in us the sensation of vision. That part of physics which deals with the properties of light is known as *optics.*

In order to explain the origin of light, various hypotheses have been made, the most important of which are the *emission* or *corpuscular* theory, and the *undulatory* theory.

On the *emission* theory it is assumed that luminous bodies emit, in all directions, an imponderable substance, which consists of molecules of an extreme degree of tenuity: these are propagated in right lines with an almost infinite velocity. Penetrating into the eye they act on the retina, and determine the sensation which constitutes vision.

On the undulatory theory, all bodies, as well as the celestial spaces, are filled by an extremely subtle elastic medium, which is called the *luminiferous ether.* The luminosity of a body is due to an infinitely rapid vibratory motion of its molecules, which, when communicated to the ether, is propagated in all directions in the form of spherical waves; and this vibratory motion, being thus transmitted to the retina, calls forth the sensation of vision. The vibrations of the ether take place not in the direction of the wave, but in a plane at right angles to it. The latter are called the *transversal* vibrations. An idea of these may be formed by shaking a rope at one end. The vibrations, or to and fro movements, of the particles of the rope, are at right angles to the length of the rope, but the onward motion of the wave's form is in the direction of the length of the rope.

On the emission theory the propagation of light is effected by a motion of *translation* of particles of light thrown out from the luminous body, as a bullet is discharged from a gun. On the undulatory theory there is no progressive motion of the particles themselves, but only of the state of disturbance which was communicated by the luminous body; it is a motion of *oscillation*, and, like the propagation of waves in water, takes place by a series of vibrations.

The luminiferous ether penetrates all bodies, but, on account of its extreme tenuity, it is uninfluenced by gravitation; it occupies space, and although it presents no appreciable resistance to the motion of the denser bodies, it is possible that it hinders the motion of the smaller comets. It has been found, for example, that Encke's comet, whose period of revolution is about $3\frac{1}{3}$ years, has its period diminished by about 0·11 of a day at each successive rotation, and this diminution is ascribed by some to the resistance of the ether.

The fundamental principles of the undulatory theory were enunciated by Huyghens, and subsequently by Euler. The emission theory, principally owing to Newton's powerful support, was for long the prevalent scientific creed. The undulatory theory was adopted and advocated by Young, who showed how a large number of optical phenomena, particularly those of diffraction, were to be explained by that theory. Subsequently to, though independently of Young, Fresnel showed that the phenomena of diffraction, and also those of polarisation, are explicable on the same theory, which, since his time, has been generally accepted.

The undulatory theory not only explains the phenomena of light, but it reveals an intimate connection between these phenomena and those of heat; it shows, also, how completely analogous the phenomena of light are to those of sound, regard being had to the differences of the media in which these two classes of phenomena take place.

290. **Various sources of light.**—The various sources of light are the sun, the stars, heat, chemical combination, phosphorescence, electricity, and meteoric phenomena.

The origin of the light emitted by the sun and by the stars is unknown; it is assumed by some that the ignited envelope by which the sun is surrounded is gaseous, and at a very high temperature.

As regards the light developed by heat, Pouillet has observed that bodies begin to be luminous in the dark at a temperature of

500° to 600°; above that the light is brighter in proportion as the temperature is higher.

The luminous effects witnessed in many chemical combinations are due to the high temperatures produced. This is the case with the artificial lights used for illuminations; for luminous flames are nothing more than gaseous matters containing solids heated to the point of incandescence.

Phosphorescence is the property which a large number of substances possess of emitting light when placed under certain conditions.

Spontaneous phosphorescence is observed in certain vegetables and animals; for instance, it is very intense in the glowworm and in the lampyre, and the brightness of their light appears to depend on their will. In tropical climates the sea is often covered with a bright phosphorescent light due to some extremely small zoophytes. These animalculæ emit a luminous matter so subtle that MM. Quoy and Gaimard, during a voyage under the equator, having placed two in a tumbler of water, the liquid immediately became luminous throughout its entire mass.

Decaying wood, and certain kinds of fish in a state of putrefaction, also exhibit this phenomenon. Certain substances, too, become phosphorescent by friction; while others become luminous in the dark by having been previously exposed to the sun's rays.

291. **Opaque, transparent, translucent bodies. Absorption of light.**—Bodies illuminated by a source of light present two distinct effects; one class, such as wood, metals, most stones, completely stop it; while others, such as air, glass, allow light to pass. The first class of bodies comprehends those which are called *opaque*, and the second the *transparent* and *translucent* bodies. The term translucent or diaphanous being applied to all bodies which at all emit light; while *transparency* refers only to the case of bodies through which objects can be distinctly seen. Polished glass may be called either transparent or diaphanous; but ground glass, oiled paper, thin porcelain, are translucid; for, while they transmit light, objects cannot be distinguished through them.

Of all bodies which transmit light, none can be said to be perfectly diaphanous; all extinguish, or *absorb*, a portion of the light which impinges on them. The most transparent, such as air, water, glass, gradually extinguish the light which penetrates them; and if their thickness be considerable, they may weaken it so much that no impression is produced on the eye. Thus, on the tops of high

mountains the number of stars visible to the naked eye is greater than in the plain; a phenomenon arising from the fact, that in the former case the layer of air traversed is not so thick as in the latter case. In like manner too the sun appears less luminous when on the horizon, for then its rays traverse thicker layers of air.

Just as there are no perfectly transparent substances, so too there are none which are quite opaque; at any rate, when the thickness is inconsiderable. Gold, which is one of the densest metals, when beaten out in the form of fine leaf, allows an appreciable quantity of light to traverse it.

Foucault has recently shown, that when the object glass of a telescope is thinly silvered, the layer is so transparent, that the sun can be viewed through it without danger to the eyes, since the metallic layer reflects the greater part of the heat and light; the tint appears slightly bluish, while in the case of gold it is greenish.

292. **Propagation of light.**—A *medium* is any space or substance which light can traverse, such as a vacuum, air, water, glass, etc. A medium is said to be *homogeneous* when its chemical composition and density are the same in all parts; conditions which are independent of each other. The atmosphere, for instance, has everywhere the same composition, but not the same density, owing to the variations in pressure and temperature, to which it is subject in various places.

Experiment shows that in *every homogeneous medium light is propagated in a right line.* For, if an opaque body is placed in the right line which joins the eye and the luminous body, the light is intercepted. In like manner we cannot receive any impression of light through a series of holes in opaque plates, superposed in each other, excepting these holes are in a straight line. The light which passes into a dark room by a small aperture, leaves a luminous trace, which is visible from the light falling on the particles suspended in the atmosphere.

Light emanates from luminous bodies in all directions, for we see them equally in all positions in which we are placed round them.

Light changes its direction on meeting an object which it cannot penetrate, or when it passes from one medium to another. These phenomena will be described under the heads *reflection* and *refraction.*

This emanation of light in all directions about a luminous body is called radiation, as in the case of heat: a *luminous ray*, or *ray of light*, is the line in which light is propagated; a *luminous pencil*, or

pencil of light, is a collection of rays from the same source. It is said to be *parallel*, when it is composed of parallel rays; *divergent*, when the rays separate from each other; and *convergent*, when they tend towards the same point. Examples of these will occur in the study of mirrors and of lenses.

293. **Shadow. Penumbra.**—When light falls upon an opaque

Fig. 206.

body, it cannot penetrate into the space immediately behind it, and this space is called the *shadow*.

In determining the extent and the shape of shadow projected by a body, two cases are to be distinguished: that in which the luminous source is a single point, and that in which it is a body of any given extent.

In the first case, let L (fig. 206) be the luminous point, and M a

Fig. 207.

spherical body, which causes the shadow. If an infinitely long straight line move round the sphere M, always passing through the point L, this line will produce a conical surface, which, beyond the sphere, separates that portion of space which is in shadow from that

which is illuminated. In the present case, on placing behind the opaque body a screen, the limit of the shadow will be sharply defined. This is not, however, usually the case, for luminous bodies have always a certain magnitude, and are not merely luminous points; the shadow formed by a luminous point is called the *geometrical shadow.*

In the second case let L (fig. 207) be a luminous sphere, and let a tangent, *bu*, be drawn externally to this sphere and the sphere M. Assuming that this line moves tangentially round the two bodies, it will produce on the screen a circle, *no*, completely in darkness. If now a second straight line, *bm*, be drawn tangentially on the inside of the two spheres, it will produce a cone on the screen, the summit of which is at S, and the base on the screen is the circle *un*, which is greater than the circle *no*. The circular space between the two circumferences is neither entirely in the shadow, nor entirely in the light, for it is only illuminated by a part of the body L; whence arises the name *penumbra*. Under ordinary conditions in which luminous bodies have a certain size, shadows are always surrounded by a penumbra. This decreases in intensity from the centre towards the edges, and has a greater extent the nearer the luminous body is to the body illuminated, and the more distant the screen.

Fig. 208.

294. **Velocity of light.**—Light moves with such a velocity that at the surface of the earth there is, to ordinary observation, no appreciable interval between the occurrence of any luminous phenomenon and its perception by the eye. And, accordingly, this velocity was first determined by means of astronomical observations. Römer, a Danish astronomer, in 1675, first deduced the velocity of light from an observation of the eclipses of Jupiter's first satellite.

Jupiter is a planet round which four satellites revolve, as the moon does round the earth. This first satellite, E (fig. 208), suffers *occultation*—that is, passes into Jupiter's shadow—at equal intervals of time, which are 42 h. 28 m. 36 s. While the earth moves in that part of its orbit, *ab*, nearest Jupiter, its distance from that planet does not materially alter, and the intervals between two successive occultations of the satellite are approximately the same; but in proportion as the earth moves away in its revolution round the sun, S, the interval between two occultations increases; and when, at the end of six months, the earth has passed from the position T to the position T′, a *total* retardation of 16 m. 36 s. is observed between the time at which the phenomenon is seen and that at which it is calculated to take place. But when the earth was in the position T, the sun's light reflected from the satellite E had to traverse the distance ET, while in the second position the light had to traverse the distance ET′. This distance exceeds the first by the quantity TT, for, from the great distance of the satellite E, the rays ET and ET′ may be considered parallel. Consequently, light requires 16 m. 36 s. to travel the diameter TT′ of the terrestrial orbit, or twice the distance of the earth from the sun.

To give some idea of this enormous velocity, it may be remarked that a cannon ball would require more than seventeen years to traverse the distance from the earth to the sun, while light would require 8 minutes and 18 seconds.

Spite of the enormous velocity of light, the stars nearest the earth are separated from it by at least 206,265 times the distance of the sun. Consequently, the light which they send requires $3\frac{1}{4}$ years to reach us. Those stars which are only visible by means of the telescope, are possibly at such a distance that thousands of years would be required for their light to reach our planetary system. We may hence form an idea of the immensity of the heavens, and how small is our globe in comparison with this infinity.

295. **Intensity of light. Law of its decrease. Photometer.**—The intensity of a source of light, that is, the energy of its illuminating power, is measured by the quantity of light which it sends on a given surface; for example, a screen a yard square. From the property which luminous rays have of diverging, this quantity of light, this intensity, decreases rapidly as the illuminated body is removed from the luminous body. It may be shown by geometrical considerations, that the intensity of light is inversely as *the square of the distance*; that is, that when the distance of an illu-

minated body from the source of light is doubled, it receives one-fourth the amount of light; at three times the distance, one-ninth, and so forth.

This law may be demonstrated by the aid of an apparatus called a *photometer*, from two Greek words which signify *measure of light.* It consists of a ground glass screen fixed vertically on a wooden base (fig. 209). In front of this screen is an opaque rod B, beyond which are the lights to be compared, in such a manner that the

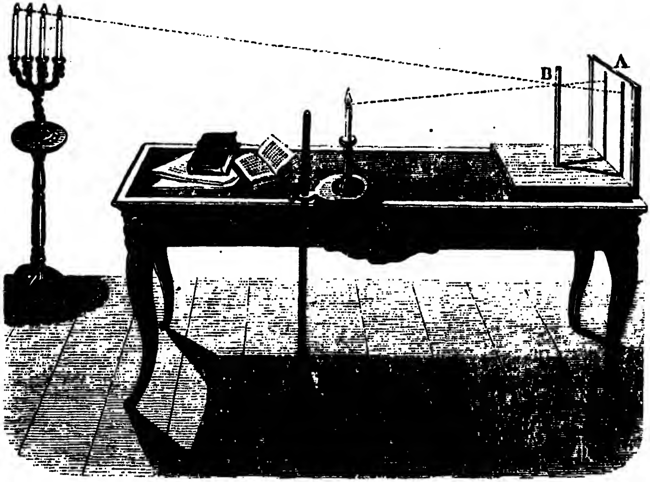

Fig. 209.

shadows of the rod form on the screen. Now it will be observed, that when the two lights have the same illuminating power, the depth of the shadows is the same; but if one of the sources of light is more powerful than the other, the corresponding shadow is deeper; and in order that the shadows be of equal intensity, the more powerful light must be removed further away.

These details being premised, the law of the decrease of light may be demonstrated as follows: In a dark room, a candle is placed at any distance from the photometer, a yard for instance; and then, at double the distance, four of the same kind of candles are placed in the same line, in the direction of the opaque rod. The two shadows on the screen will then be found to have exactly the same depth; which shows that, at two yards' distance, four candles have no

more illuminating power than one candle at a distance of one yard; from which it is concluded that each of them, at double the distance, has one quarter the illuminating power. It may also be shown in the same manner, that nine candles, at three yards only, have the same illuminating power as one at a yard, and so forth, which proves the law.

It is important to observe, that it is in consequence of the divergence of luminous rays that light decreases as the distance increases. This decrease does not obtain in the case of parallel rays; their lustre would be the same at all distances, were it not for the absorption which takes place in even the most diaphanous media.

CHAPTER II.

REFLECTION OF LIGHT. MIRRORS.

296. **Laws of the reflection of light.**—When a luminous ray meets a polished surface, it is not destroyed by this obstacle; but

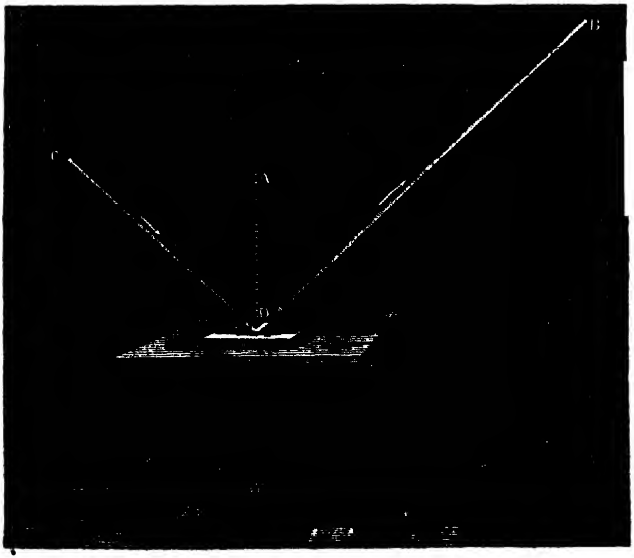

Fig. 210.

bounds off from it, changing its direction, and this phenomenon is termed *the reflection of light*. Thus, if through a hole in the shutter of a dark room, a pencil of solar light, CD, be allowed to enter, and it be received on a plane mirror, this pencil is reflected in the direction DB, and forms on the ceiling an image, the shape of which will be discussed in speaking of the camera obscura.

As in speaking of the reflection of calorific rays (205) the ray CD is the *incident ray*, BD is the *reflected ray*, and the straight line AD at right angles to the mirror is the *normal*. Lastly, the angles CDA and ADB are called respectively the *angles of incidence* and the *angles of reflection*.

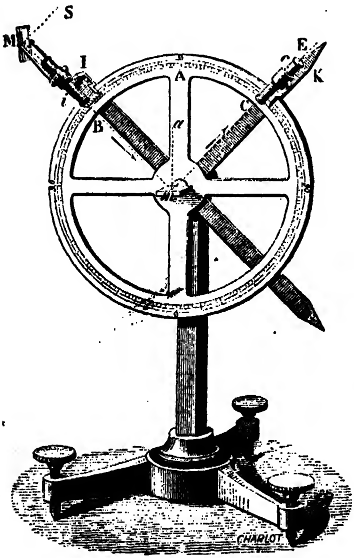

Fig. 211.

The reflection of light is governed by the following two laws, which, as we have seen, also prevail for heat:—

I. *The angle of reflection is equal to the angle of incidence.*

II. *The incident and the reflected ray are both in the same plane, which is perpendicular to the reflecting surface.*

First proof. The two laws may be demonstrated by the apparatus represented in fig. 211. It consists of a graduated circle in a vertical plane, on three levelling screws. Two brass slides, I and K, move round the circumference. They support two small tubes *i* and *c*, directed exactly towards the centre, and intended to give passage respectively to the incident and reflected rays. On the slide I there is, moreover, a small mirror M, which can be inclined at will. The zero of the graduation is at A, and extends to 90 degrees on each side.

These details being known, the slide I having been more or less removed from zero, the mirror, M, is inclined so that a luminous ray, S, after having been reflected on this mirror, should pass

through the tube *i*, and fall upon a second mirror, *m*, arranged horizontally in the centre of the circle : there the luminous ray is reflected a second time, and takes the direction *m*E. The slide K is then removed to or from A, until the eye being placed at E, the reflected ray, *m*E, is received through the tube *c*. If, now, the number of degrees contained in the arcs AB and AC be read off, they will be found to be exactly equal. Hence the angles of incidence and of reflection B*ma* and *am*C, measured by their arcs, are equal, which verifies the first law.

The second law is also verified ; for, in the construction of the apparatus, care is taken that the axes of the tubes, *i* and *c*, are in one and the same plane parallel to that of the graduated circle, and therefore perpendicular to the surface of the small mirror *m*, and containing the normal *ma*.

In the above drawing the direction in which light is propagated is represented by arrows ; the same will be the case with all optical diagrams, which we shall have occasion to introduce.

297. **The reflection in light is never complete.**—The light which falls upon a body is never completely reflected ; a certain portion is always extinguished, absorbed by the reflecting surface. If we represent by 100 the quantity of incident light, the reflected portion will be 80, 90, 95, according to the nature and degree of polish of the reflecting body ; but it will never amount to 100.

The best reflectors are polished metals, especially if they are white like mercury, and silver. Black bodies reflect no light. Translucent substances reflect a small quantity, and absorb more or less according to their thickness, while they transmit the remainder. This is what takes place with air, water, glass, and all transparent media.

For one and the same substance the quantity of reflected light increases not only with the degree of polish, but with the obliquity of the incident ray. For instance, if a sheet of white paper be placed before a candle, and be looked at very obliquely, an image of the flame is seen by reflection, which is not the case if the eye receives less oblique rays.

The intensity of the reflection varies with different bodies, even when the degree of polish and the angle of incidence are the same. It also varies with the nature of the medium which the light is traversing before and after reflection. Polished glass immersed in water loses a great part of its reflecting power.

298. **Irregular reflection. Diffused or scattered light.**—The

reflection from the surfaces of polished bodies, the laws of which have just been stated, is called the *regular* or *specular reflection*: from a Latin word signifying mirror : but the quantity thus reflected is less than the incident light. The light incident on an opaque body actually separates into three parts; one is reflected regularly, another *irregularly*, that is, in all directions; while a third is extinguished, or absorbed by the reflecting body.

Thus, if in the experiment represented in fig. 210, the beam, CD, be caught on an unpolished surface instead of on a mirror, not only will it be seen in the direction DB, corresponding to regular reflection, but it will be seen in all positions in the dark room; whence it is concluded that light is reflected in all directions and under all obliquities; which is contrary to the laws of reflection.

The irregularly reflected light is called *scattered* or *diffused light*: it is that which makes bodies visible; it has its origin in the structure of bodies themselves, which, from their roughness, present an infinity of small facettes variously inclined, and reflecting light in all directions.

Diffused light plays an important part in the phenomena of vision. For while luminous bodies are visible of themselves, opaque bodies are only so in consequence of the diffused light which they send in all directions. Thus when we look at a piece of furniture, a table, a flower, it is the diffused light reflected on all sides, and in all directions, by the object which enables us to see them in whatever direction we may be placed in reference to the light which illuminates them. When luminous bodies only reflect light regularly, it is not them we see, but, acting like mirrors, they only give us the image of the luminous body whose light they send towards us. If, for example, a solar beam be incident on a well-polished mirror in a dark room, the more perfectly the light is reflected the less visible is the mirror in the different parts of the room. The eye does not perceive the image of the mirror, but that of the sun. If the reflecting power of the mirror be diminished by sprinkling on it a light powder, the solar image becomes feebler, and the mirror is visible from all parts of the room. Perfectly smooth polished reflecting surfaces, if such there were, would be invisible, and absolutely non-reflecting surfaces would also appear all equally black, and would be confounded with each other. Two bodies, one white and the other black, placed in darkness, are quite invisible, for that which is white, not receiving any light, can reflect none.

It is the diffused light reflected by the air, by the clouds, by the

ground which illuminates our rooms and all bodies not directly exposed to the sun's rays; and the more diffused light a body sends towards us, the more precisely can we distinguish it. From the inside of our rooms we well see external objects, for they are powerfully illuminated; but from the outside we only see confusedly in the interior of apartments the objects found there, for they receive little light.

299. **Direction in which we see bodies.**—Whenever a luminous pencil passes in a straight line from a body to our eye, we see it exactly as it is; but if in consequence of reflection, or any other cause, the pencil or light is deviated in its route, if it ceases to

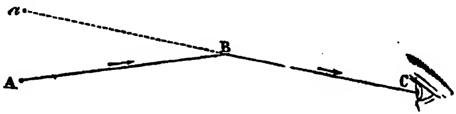

Fig. 212.

come to us in a straight line, we no longer see the body in its proper place, but *in the direction of the luminous pencil at the moment it enters the eye.* Thus if the pencil AB is deflected at B (fig. 212), and takes the direction BC, the eye does not see the point A at A but at *a*, in the prolongation of CB.

This principle is general, and, though very simple, well deserves the attention of the reader, for on it are based the numerous effects of vision which mirrors and lenses present.

MIRRORS.

300. **Mirrors. Images.**—*Mirrors* are bodies with polished surfaces, which show by reflection objects presented to them. The place at which objects appear is their *image.* According to their shape, they are divided into *plane* and *curved* mirrors.

We have an example of a plane mirror in the looking glasses which adorn our apartments. In these mirrors it is not the glass which reflects light in sufficient quantity to give neat and well defined images; it is a metallic layer on the back of the glass. This layer is an *amalgam* of tin, that is, an alloy of this metal with mercury. The glass only has the effect of giving the metal the necessary polish, and to preserve it from external agencies tending to tarnish it.

Metal mirrors are also constructed of gold, silver, steel, tin.

They have all the defect of tarnishing on contact with the air; yet they were in frequent use among the Romans. We cannot go back to the origin of mirrors. The first was doubtless the surface of limpid water. Those of metal appear to be of high antiquity, for mention is made in Exodus of a bronze ewer, made by Moses with the mirrors offered him by the Israelitish women.

301. **Formation of images in plane mirrors.**—*Plane mirrors* are those whose surface is plane; such, for example, are the pier glasses which adorn the chimney-pieces of our rooms. To understand the formation of images in these mirrors, let us first consider the case in which a very small object is placed in front of such a

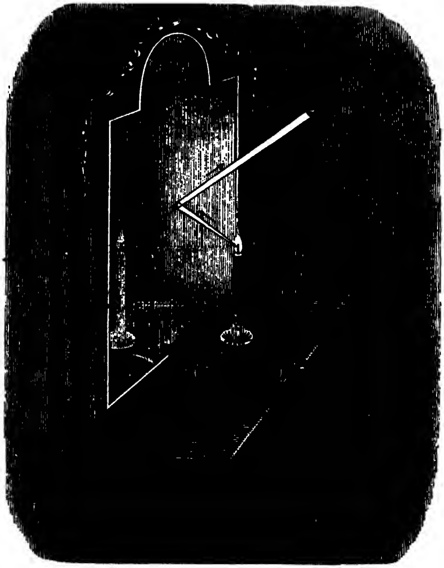

Fig. 213.

mirror; for instance, the flame of a candle (fig. 213). A divergent pencil of light emitted by this flame and falling on the mirror is reflected there, as shown in fig. 213. But it follows from the laws of reflection, that each ray of this pencil retains, in reference to the mirror, the same obliquity as it had before; whence it follows, that the reflected rays have the same divergence in reference to

each other as the incident rays. Hence if we imagine the reflected pencil prolonged behind the mirror, all the rays composing it will coincide in the same point. But as we always see objects in the direction the luminous rays have when they reach us (299), it follows that the eye which receives the reflected pencil should see the flame of the candle just in the place where the prolongation of these reflected rays coincide. There, in fact, is produced the image of this flame as seen in fig. 213.

If now, instead of supposing a very small object placed in front of the mirror, we consider a body of any dimensions, in order to understand the formation of its image we need do no more than apply to each of its parts what has been said in reference to a single lumi-

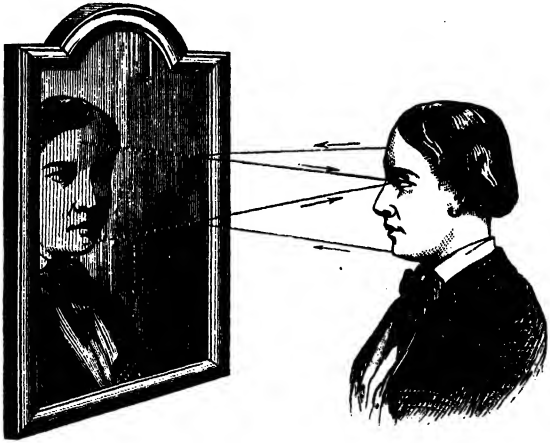

Fig. 214.

nous point; for instance, in fig. 214, which represents a person in front of a mirror, the rays from the forehead, for instance, are reflected from the mirror and return to the eye, producing an image of the forehead. In like manner the rays from the chin being reflected from the mirror reach the eye as if they proceeded from the chin of the image, and so on with all parts of the face; hence the illusion which makes us see our image on the other side of the mirror.

302. **Nature of the images in plane mirrors. Real and virtual images.**—When looking in a mirror we raise the right

hand, it is the left which seems raised in the mirror; and if we raise the left hand the right seems raised. We should falsely express this transposition of the parts of the image in reference to the object if we merely say that the image was reversed; if it were nothing else than the object reversed, in raising the right hand the image should also raise the right hand, while it really is the left which is raised.

This special equality which exists between an object and its image is expressed by saying, that the image is *symmetrical* in reference to the object; that is, that any point of the image is arranged behind the mirror in identically the same manner as the corresponding point of the object in front. For it may be shown by geometrical considerations, that these two points are equidistant from the mirror, and on the same right line, which is at right angles to the surface. From the respective distance and position of the different parts of the object and of its image, it is concluded that the latter is of the same magnitude as it, and equidistant from the mirror.

Lastly, images formed in plane mirrors are *virtual*, by which we mean, that they have no real existence, and are only an illusion of the eyes. For in fig. 213 as well as in fig. 214 the light, as it does not pass behind the mirror cannot form any image there, and that which we see has no existence: this is expressed by the word *virtual* as opposed to *actual* or *real*. Virtual images are only an optical illusion; but we shall soon see that, in concave mirrors and in lenses, *real* images are produced which can be received on screens; this is not the case with virtual images.

We may thus sum up what we have said: *images in plane mirrors are symmetrical in reference to the object, of the same magnitude, at the same distance on the other side of the mirror, and are virtual.*

303. **Multiple images formed by glass mirrors.**—Metallic mirrors which have but one reflecting surface only give one image; it is different with glass mirrors, the two surfaces of which reflect, though unequally. For if we apply any object, the point of a pencil, for instance, against a thick piece of polished glass at first, when it is looked at obliquely a very feeble image is seen in contact with it; then, beyond it, another and far more intense one. The first image is due to the light reflected from the anterior surface of the plate; that is, on the glass itself, while the second is due to the light which, penetrating into the glass, is reflected from the layer of metal by

which the posterior face is covered. The difference in intensity of the two images is readily explained; glass being very transparent, only a small quantity of light is reflected from the first face of the mirror, which gives the least intense image; while the greater part of the incident light passing into the mass is reflected from the surface of the metal, and gives the most luminous image.

The above experiment furnishes a simple means of measuring the thickness of a glass mirror. For the more intense image should appear behind the layer of metal at the same distance as the point of the pencil in front; and it follows thence, that the distance between the point of the pencil and the point of its image is double the thickness of the mirror. If this distance seems to be the eighth of an inch, it will be concluded that the real thickness is $\frac{1}{16}$th of an inch.

The double reflection from mirrors is prejudicial to the sharpness of the images, so that, in scientific observations, metallic mirrors are preferred to glass ones.

Fig. 215.

304. **Reflection from transparent bodies.**—We have seen that glass, spite of its transparency, reflects a sufficient amount of light to give images, which, though feeble, are distinct. The same is the case with water and other transparent liquids. Thus, on the borders of a pool, we see formed in the water the reversed image of objects on the opposite bank. We say *reversed* image, so as to

express the appearance; but rigorously we should say symmetrical, from what we have before said (302).

Fig. 216 represents the phenomenon of reflection from the surface of water; it shows how the reflected rays, reaching the eye in an upward direction, reproduce the image of objects situated above the water, just as they would if reflected from a horizontal mirror.

CURVED MIRRORS.

305. **Concave mirrors.**—There are many kinds of curved mirrors; those most in use are called *spherical mirrors*, from their curvature being that of a sphere. They may be either of metal or of glass, and are either *concave* or *convex*, according as the reflection is from the internal or the external face of the mirror. A curved watch glass, seen from above, gives an idea of a convex mirror, especially if it is covered by a coating of metal on the inside; the same glass coated externally and seen from the inside becomes a concave mirror.

We shall first investigate concave mirrors, and, to facilitate the investigation, will first consider what is called a *section*; that is, the figure obtained by cutting it into two equal parts. Let MN be the section of a spherical mirror, and C the centre of the corresponding sphere. In reference to the sphere this point is called the *centre of curvature*; the point A is the *centre of the figure*.

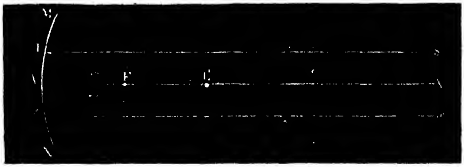

Fig. 216.

The infinite right line, ACX, which passes through A and C, is the *principal axis* of the mirror: any right line, *iCd*, which simply passes through the centre C, and not through the centre of figure A, is a *secondary* axis. The angle MCN, formed by joining the centre and extremities of the mirror, is the *aperture*. A *principal* or *meridional section* is any section made by a plane through its principal axis. In speaking of mirrors those lines alone will be considered which lie in the same principal section. There is only one principal axis, but the number of secondary axes is unlimited.

The theory of the reflection of light from curved mirrors is easily deduced from the laws of reflection from plane mirrors, by considering the surface of the former as made up of an infinitude of extremely small plane surfaces, all equally inclined to each other so as to form a regular spherical surface. Thus, on this hypothesis, when a ray of light falls upon any point whatever of a curved mirror, it is really from a small plane mirror that it is reflected; the reflection takes place then in accordance with the laws already laid down (296).

306. **Focus of concave mirrors.**—The small facettes, of which we have assumed concave mirrors to be made up, being all inclined towards a common centre, which is the centre of curvature of the mirror, it follows from this obliquity that the rays reflected by their mirrors tend to unite in a single point, which is called the *focus*, as we have already seen in the case of heat (201).

To explain this property of curved mirrors let SI be a ray falling

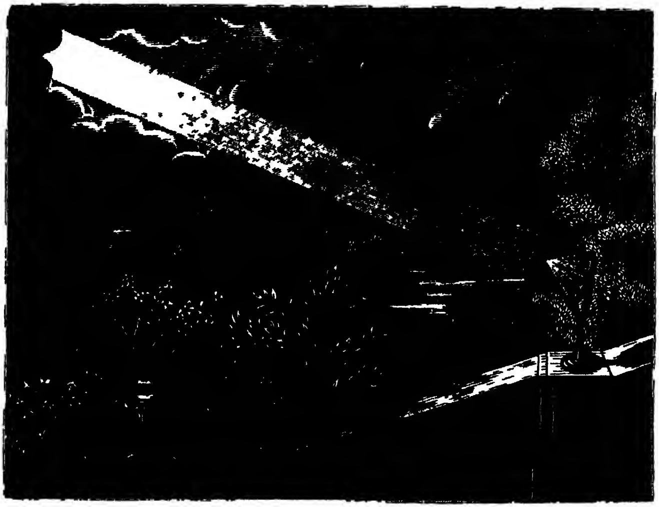

Fig 217

upon such a mirror parallel to the axis AX (fig. 217). From the hypothesis assumed above, the reflection takes place at I, on an infinitely small plane mirror. It can be shown by geometrical con-

siderations, that the normal to this small mirror is represented by the right line CI from the centre to the point I. Hence the angle SIC represents the angle of incidence; and if we imagine, on the other side of the normal, a straight line IF, which makes with CI an angle FIC, equal to CIS, this straight line will be in the direction of the reflected ray.

But when the incident rays are parallel to the axis of the mirror, as in the above example, it may be proved by geometrical considerations, that the point F, where the luminous ray cuts the axes, is the middle of AC; that it is equidistant from the centre and the mirror. This property being common to all rays parallel to the axis, it follows that, after reflection, these rays will all coincide in the same focus, F, as shown in the figure.

The focus described above that formed at an equal distance from the centre and from the mirror, is called the *principal focus;* it is produced whenever the rays falling on the mirror are parallel to its axis. An example of this is seen in fig. 218, which represents a pencil of solar light falling upon a concave mirror. If where the reflected rays tend to concentrate themselves a small ground glass screen be placed, a very luminous point will appear, which is the principal focus.

307. **Conjugate focus.**—In the preceding examples we have considered the case of pencils of parallel rays, which presupposes a luminous object at an infinite, or at all events a very great, distance. Let us now consider the case in which the source of light being at a small distance, the rays falling on the mirror are

Fig. 218.

divergent, as shown in fig. 218. Here the reflected rays are converged, but less so than in figs. 216 and 217, which results from the

divergence the light has in arriving on the mirror. Hence the point where the reflected rays coincide is more distant: instead of being at F equidistant from the mirror and the centre, it is at *b*, between the points F and C. This point, *b*, where the rays coincide, is also a focus. To distinguish it from the principal focus F, it is called the *conjugate focus*, from a Latin word meaning *connected*; for there is between the position of the luminous point B and that of this focus this connection, that when the luminous object is at B, the rays form their focus at *b*; and that conversely, if the luminous point is removed to *b*, the reflected rays form their focus at B.

We have seen that there is only a single position for the principal focus, which is at an equal distance from the centre and from the mirror: this is not the case with the conjugate focus, the position of which is very variable. For suppose that in fig. 218 the candle is removed away from the mirror, as the incident rays make then, with the normal, *cm*, gradually increasing angles of incidence, the angles of reflection, *cmb*, increase too, and the focus *b* approaches the point F, with which it will ultimately coincide, when the candle is so far distant that the incident rays are virtually parallel.

If, on the contrary, the candle is brought nearer the mirror, the rays falling upon it make with the normal, *cm*, angles which are gradually smaller, the angles of reflection, *cmb*, decrease also. Hence the rays sent by the mirror concur at gradually greater distances, the focus *b* advances towards the centre *c*; and if the candle comes nearer the point, so as to coincide with it, the case will be the same with the focus *b*; so that the candle and its image will coincide at *c*.

Lastly; if the candle always approaching the mirror passes between the centre and the principal focus F, the conjugate focus *b*, continually removing from the mirror, passes on the other side of the centre, and is formed at a greater distance the nearer the luminous body is to the principal focus; if the candle coincides with this latter point, the conjugate focus forms at an infinite distance, and the reflected rays become parallel.

These different effects of reflection are a consequence of the constant equality between the angle of incidence and the angle of reflection. They are very simply verified by placing in a dark room a candle in front of a concave mirror successively in various positions, and then ascertaining by trial where the luminous focus

is formed, on a small screen of paper held in the hand, and which is approached to or receded from the mirror.

308. **Virtual focus.**—After having described the different positions of the point in which the rays reflected by a concave mirror coincide, when the luminous body is either beyond or in the principal focus, we have to inquire what becomes of these same rays when the source of light is in any point, P, which is nearer the mirror than the principal focus (fig. 219). In this case the reflected rays form a diverging pencil, and cannot therefore produce any focus in front of the mirror; but as regards the eye which receives them, they produce exactly the same effect as in plane mirrors (301); that is, it receives exactly the same impression from the reflected rays LM and *im*, as if the candle were placed behind the mirror at the point *p*, where the prolongation of these rays coincide.

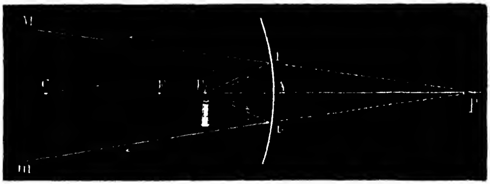

Fig. 219.

Hence the image of the candle is seen at *p*, but as the light does not penetrate behind the mirror, this image does not really exist: hence the focus which seems to form at *p* is called the *virtual* focus, the expression being understood in the same sense as in plane mirrors.

309. **Formation of images in concave mirrors.**—Concave mirrors give rise to two kinds of images, real and virtual. Their formation is readily understood after what has been said respecting the conjugate and the virtual focus. We may however remark, when a luminous or illuminated point is situate on the principal axis of a mirror, its focus, real or virtual, is always formed on this axis. This is the case in figs. 218 and 219, but if the luminous point is on a secondary axis, the focus is formed on this axis. Thus, if in fig. 216 a candle were placed at *d*, on the secondary axis, *i*C*d*, the reflected rays would form their focus on the line C*i*. That being admitted, let us see how images are formed in concave mirrors.

Real image. If a person places himself at a certain distance in front of a concave mirror, he no longer sees himself erect and of the ordinary size, as in plane mirrors, but reversed, and much smaller, as shown in fig. 220. To this image is given the name *real image*, to express that it is not an illusion as that seen in plane mirrors, but that it has a real existence. For it may be caught on a screen. If the mirror be placed in front of an object powerfully illuminated, as, for instance, before a building on which the sun is shining, and a person places himself a little on one side, holding a small white screen in the position in which the conjugate focus should be formed, the pencils from the various parts of the

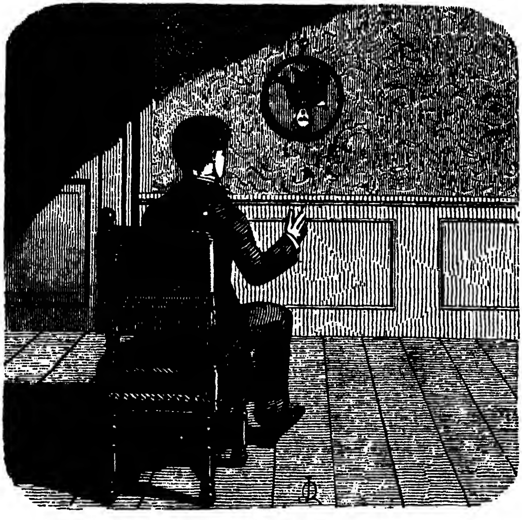

Fig. 220.

edifice are reflected from the mirror and fall on the screen, forming in miniature an image not less remarkable for the colour, than for the fidelity of the contours (fig. 221): it has no other defect than that of being reversed.

The formation of this image is readily explained. For from what has been said in reference to conjugate foci (307), each point of the image is the conjugate focus of the corresponding point of the illuminated body, and is on the same secondary axis.

But as all the secondary axes from the various points of this body cross in the centre of curvature of the mirror, it follows, as shown in the figure, that the rays emitted by the higher parts of the body converge towards the lower part of the image, and that reciprocally rays from the foot unite on the higher parts of this same image, which explains how it is the latter is reversed.

It is to be observed that the real image in concave mirrors is not always smaller than the object illuminated, as is the case in the above two figures; it may also be larger. This is the case

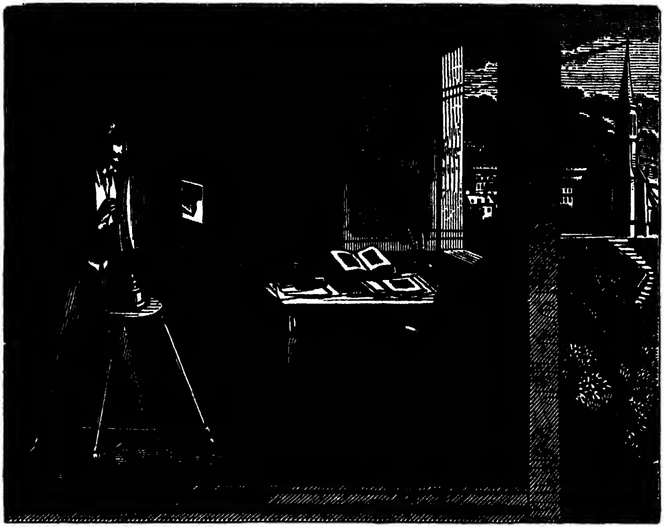

Fig. 221.

when, the object being placed between the principal focus and the centre of curvature, its image is formed outside the latter, and it is then larger the greater the distance at which it is formed.

Virtual image. The above figure (220) shows how, when a person is placed at a certain distance in front of a concave mirror, he sees himself smaller and reversed. If he comes nearer, there is a point at which no image is seen. This is the case when he is between the centre and the principal focus, for the image is thus formed behind the observer. If he is in the principal focus itself,

there is no image. For we know (307) that the luminous rays proceeding from this focus, after being reflected from a concave mirror, produce a parallel luminous pencil: hence, as the rays coincide neither behind nor in front of the mirror, they cannot give rise to any image. But, approaching the mirror, the image suddenly reappears, and instead of being smaller and reversed as it was, is now erect and much enlarged, as in fig. 222. This is the *virtual image.*

Fig. 222.

To account for the formation of this image we must recall what has been said about the virtual focus (308): First, that it is only formed as long as the luminous or illuminated object is between the principal focus and the mirror; second, that the virtual focus, or, what is the same thing, the virtual image of any point of the object, is behind the mirror on the

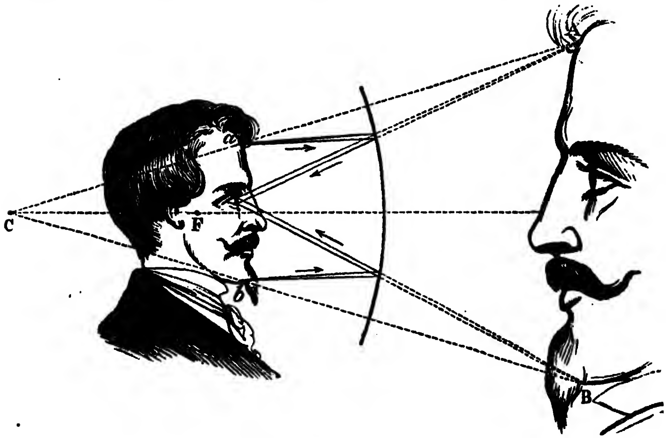

Fig. 223.

secondary axis which passes through this point. Hence, the head of the observer being placed between the mirror and the principal

focus (fig. 223), all rays from any point, *a*, of the face return to the eye after reflection, as if they proceeded from the point, A, where the prolongations of the reflected rays coincide on the secondary axis, C*a*A. In like manner, rays from the point *b* return to the eye, as if they were emitted from the point B, which is on the prolongation of the secondary axis, C*b*B. The eye sees, therefore, at AB, an erect and enlarged image.

Fig. 224.

310. **Formation of images in convex mirrors.** — We have already seen that convex mirrors are spherical mirrors, which reflect light from their external surface, that is, on their bulbed side. Whatever the distance of a luminous or illuminated object placed in front of these mirrors, we never obtain any other than a virtual image situated on the other side of the mirror, always erect, and smaller than the object. This may be verified by looking in a mirror of this kind, as re-

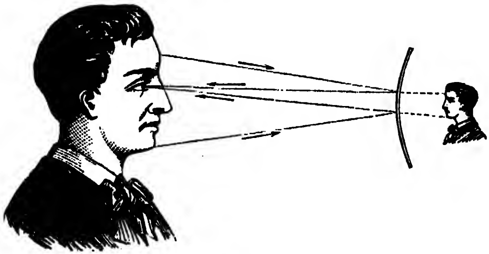

Fig. 225.

presented in figure 224. The formation of this image can be easily explained by an inspection of figure 225. It is here smaller than the object, for it is nearer than it to the point where the secondary axes coincide, while the reverse is the case with the formation of the virtual image in concave mirrors.

311. **Applications of mirrors.** — The applications of plane mirrors in domestic economy are well known. Mirrors are also frequently used in physical apparatus for sending light in a certain direction. The solar light can only be sent in a constant direction by making the mirror movable. It must have a motion which compensates for the continual change in the direction of the sun's rays produced by the apparent diurnal motion of the sun. This result is obtained by means of a clock-work motion, to which the mirror is fixed, and which causes it to follow the course of the sun. This apparatus is called the *heliostat.* The reflection of light is also used to measure the angles of crystals by means of the instruments known as *reflecting goniometers.*

Concave spherical mirrors are also often used. They are sometimes applied for *magnifying mirrors,* as in a shaving mirror. They have been employed for burning mirrors, and are still used in telescopes. They also serve as reflectors, for conveying light to great distances, by placing a luminous object in their principal focus. For this purpose, however, parabolic mirrors are preferable.

CHAPTER III.

REFRACTION OF LIGHT.

312. **Phenomenon of refraction.**—When a ray of light passes more or less obliquely from one transparent medium into another; for instance, from air into water, or from air into glass, it undergoes a deflection from the straight line which it traverses, as seen in fig. 226, which represents a ray of light passing from air into water. This change in direction is called *refraction,* from a Latin word meaning *broken*; for the ray is, in fact, broken at the point A, where it passes from the direction LA to the direction AK.

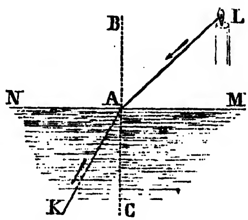

Fig. 226.

The ray, LK, is called again the *incident ray*; AK is the *refracted ray*; the perpendicular, BC, drawn at the point of incidence, A, of the surface, MN, which separates the two media, is called the

normal; lastly, the angle, BAL, is called the *angle of incidence;* and the angle, CAK, the *angle of refraction.* If the angle of incidence is null, that is, if the incident ray coincides with the normal, the same is the case with the refracted ray, and light travels in this case in a straight line.

313. **Laws of refraction.**—When a luminous ray is refracted in passing from one medium into another of a different refractive power the following laws prevail:

I. *Whatever the obliquity of the incident ray, the ratio which the sine of the incident angle bears to the sine of the angle of refraction, is constant for the same two media, but varies with different media.*

II. *The incident and the refracted ray are in the same plane, which is perpendicular to the surface separating the two media*

These laws may be understood by reference to the adjoined figure (227), in which the ray, LA, passes from air into water. If from the point of incidence, with a radius equal to unity, a circle be described, and from the points, *m* and *p*, where it cuts the incident and refracted rays, perpendiculars, *mn* and *pq*, are drawn to the normal, BC, the former is called the *sine of the angle of incidence*, and the second the *sine of the angle of refraction.*

Fig. 227.

It is the ratio of these sines, these perpendiculars, which is constant; that is, that *pq*, for instance, being three-quarters of *mn*, if the angle of incidence diminishes or increases, the angle of refraction does so too, but the sine of the latter will always be three-quarters of the sine of the former.

This constant ratio is called the *refractive index*, or *index of refraction*; its value varies with different transparent media.

314. **Refracting substances.**—When a ray of light is refracted in passing from one medium into another, sometimes it approaches the normal, forming an angle of refraction, which is less than the angle of incidence, as is the case in the above figure; sometimes, on the contrary, it is deflected away, forming an angle of refraction, which is greater than the angle of incidence. In the first case the second medium is said to be more *refringent* or *refractive* than the first, and in the second case it is less so.

Among the most refringent bodies are water, alcohol, ether, the fat oils, etc. Diamond is the most refringent of all bodies. Gases

are less refringent than water; their refracting power is increased by condensing them, that is, by increasing their density.

315. **Experimental proofs of refraction.**—The deviation undergone by luminous rays, on passing from one medium to another, may be demonstrated by numerous experiments. Thus, if in a dark room a pencil of solar light be allowed to fall on a glass vessel containing water (fig. 228), the pencil can be very distinctly

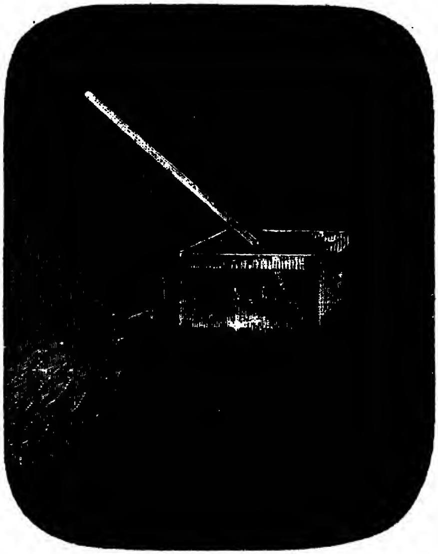

Fig. 228.

seen to be broken as it passes from air into water, especially if some light powder has been diffused through the air and the water so as to make the pencil more visible.

Or let a coin be placed at the bottom of an opaque vessel (fig. 229), and the eye be placed so that the edge of the vessel just intercepts the view of the coin. If, now, without altering the position of the observer, a little water be gradually poured into the vessel, at first only the edges of the coin will be seen, then half, and finally the entire piece. Now what has taken place here? Nothing has been changed in the position of the eye, or in that of the piece;

it is the rays from the latter which have changed their direction. Those which were before intercepted by the sides of the vessel are so still; but rays which, before there was water in the vessel, passed above the observer's head, are directed towards the eye, being refracted in passing from water into air, so as to diverge from the perpendicular to the surface of the liquid, as represented in the figure.

316. **Various effects of refraction.**—Refraction of light produces various phenomena, the effect of which is to deceive the eye by making us see objects in other than their true position; thus, we do not see fish in the place they actually occupy, but a little higher, as indicated by the path of the refracted ray in fig. 230. It will be understood that in consequence of the same phenomena we see the bottom of a river, or a pond higher than it really is; we thus consider the water to be not so deep, an illusion which may be dangerous.

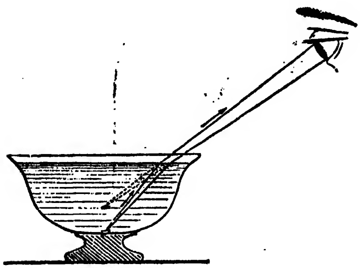

Fig. 229.

Fig. 23c.

The same cause makes a stick half immersed in water appear broken when it is looked at at the side; for the portion out of the water is seen in its true position, while that which is immersed appears raised, from which results the appearance of the stick being broken at the surface of the liquid (fig. 231).

Fig. 231.

We may, in conclusion, cite the influence which refraction exerts upon the apparent rising and setting of the stars, which we can see a little before they are above the horizon, and a little after they have sunk below it. To explain this phenomenon let us suppose the atmosphere divided into layers parallel to the surface of the globe, as represented in fig. 232. Owing to the pressure exerted by the upper layers

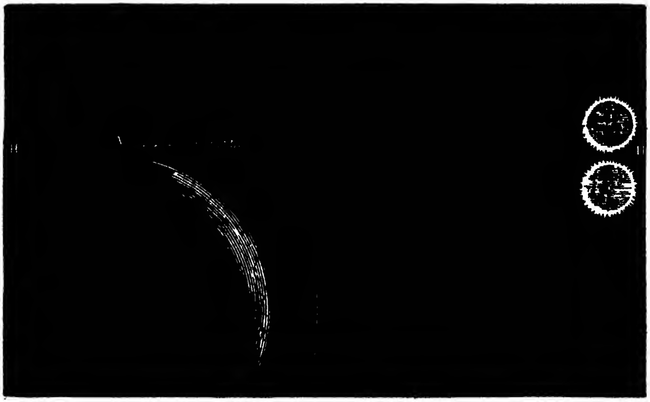

Fig. 232.

upon the lower ones, the latter are more dense, and therefore more refringent, for, as we have seen, the refracting power of the air increases with its density (314). The solar rays, which penetrate

the atmosphere, are always refracted in the same direction as they pass from one layer to another: hence their path, instead of being that of a straight line, will be really somewhat curved. Thus it is that, while the sun is at S, below the horizon, HH, an observer at A, on the surface of the earth, will see it raised by an amount which is generally equal to its apparent diameter.

317. **Change of refraction to reflection.**—Whenever light passes from one medium into a more refringent one, from air into water for instance, there is nothing to prevent the refracted ray from approaching the normal, to form an angle smaller than the angle of incidence; but if, on the contrary, the second medium is less refringent than the first, in which case the refracted rays recede from the normal, there is a limit to their deviation, and hence refraction may become impossible.

To get a clearer idea of this, let us imagine a hollow glass sphere half filled with water (fig. 233), and a ray of light, LA, to enter the liquid without being refracted, which is the case when it penetrates at right angles the small facette which we can always conceive to exist at the point at which it enters. This ray is refracted at A in passing from water into air, and diverges from the normal, BAC, in the direction AR. Now, if we conceive the luminous body to move gradually from AC, as the angle of incidence, CAL, increases, the angle of refraction, BAR, does so too; and an angle, CAL, might acquire such a magnitude as to emerge parallel to the surface, AM, of the liquid. This angle of incidence is what corresponds to the *limit of refraction*. For, for any greater angle of incidence, the angle of refraction should exceed the angle BAM; and the light would then take below AM a direction such as A*r*. There would, however, then be no refraction, for the light, always travelling through water, does not change its medium. If the incident ray be then represented by *l*A, if we measure the two angles, *l*AC and CA*r*, it will be found that they are exactly equal, which shows that at the point, A, the light is reflected according to the ordinary laws of reflection.

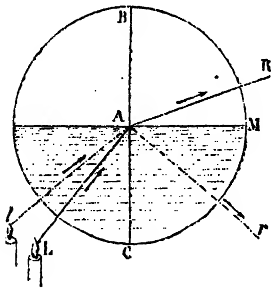

Fig. 233.

This kind of reflection at the surface, separating two media of

different refracting power, is called *internal reflection*: it is also called *total reflection*, for here the whole of the incident light is reflected, which is never the case in ordinary reflection, even in the best polished surfaces (297).

The phenomenon is frequently met with; thus, if a silver spoon be placed in a glass of water, and it be raised above the eye, the surface of the liquid is seen brighter than a polished metal, and one portion of the spoon for an image in it as in a mirror. Similar effects are met with in aquariums. The upper surface of the liquid, when looked at from a suitable position below, gives a reflected image of the objects it contains.

318. **Mirage.**—The *mirage* is an optical illusion by which inverted images of distant objects are seen as if below the ground, or

Fig. 234.

in the atmosphere. This phenomenon is of most frequent occurrence in hot climates, and more especially on the sandy plains of Egypt. The ground there has often the aspect of a tranquil lake, on which are reflected trees and the surrounding villages. In vain, however, does the traveller redouble his velocity; this imaginary lake, so desired, flees from him as he advances. The phenomenon has long been known; but Monge, who accompanied Napoleon's expedition to Egypt, was the first to give an explanation of it.

It is a phenomenon of refraction, which results from the unequal density of the different layers of the air when they are expanded by

contact with the heated soil. The least dense layers are then the lowest, and a luminous ray from an elevated object, *a* (fig. 234), traverses layers which are gradually less refracting; for, as we have shown (314), the refracting power of a gas diminishes with lessened density. The luminous ray continues its path, being, however, more and more bent from one layer to the other, until the angle of incidence, which continually increases, reaches the limit at which internal reflection succeeds to refraction (317). The ray then rises at *a*, as seen in the figure, and undergoes a series of successive refractions, but in a direction contrary to the first, for it now passes through layers, which are gradually more and more dense, and therefore more refracting. The luminous ray then reaches the eye with the same direction as if it had proceeded from a point below the ground, and hence it gives an inverted image of the object, just as if it had been reflected at the surface of a tranquil lake.

Mariners sometimes see images in the air of the shores, or of distant vessels. This is due to the same cause as the mirage, but is in a contrary direction, only occurring when the temperature of the air is above that of the sea, for then the inferior layers of the atmosphere are denser, owing to their contact with the surface of the water.

CHAPTER IV.

EFFECTS OF REFRACTION THROUGH PRISMS AND THROUGH LENSES.

319. **Media with plane parallel faces.**—When a luminous pencil traverses a transparent medium, three cases may be considered. First, that in which the medium is comprised between two parallel planes; second, that in which it is comprised between two plane surfaces inclined towards each other; thirdly, that in which the medium is comprised between two curved surfaces, or between a curved and a plane surface, which gives rise to the same effects.

We will start with the consideration of the first case, and let L*m* be a ray of light traversing a glass plate, AB, with parallel faces (fig. 235). In passing from air into glass at the point *m*, this ray approaches the normal; but as, on its emergence from the glass at

the point n, it deviates from the perpendicular by exactly the same amount, it follows that, after having traversed the glass plate, its direction On is exactly parallel to Lm; whence we conclude that light is not deviated when it traverses a medium with parallel faces, such as the glass panes in our windows.

320. **Prisms.**—In optics a *prism* is any transparent

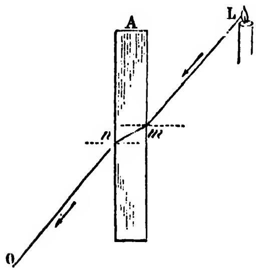

Fig. 235.

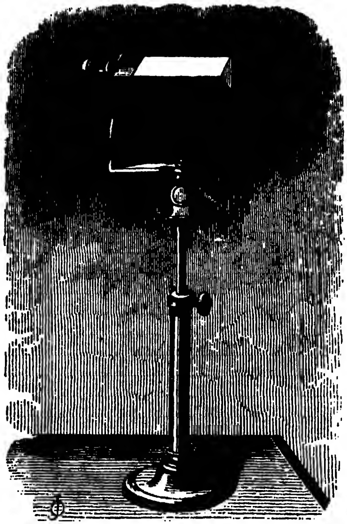

Fig. 236.

medium comprised between two plane faces inclined to each other. Thus, the facettes of a glass stopper taken in pairs form as many prisms.

Fig. 236 represents the shape and arrangement of prisms for optical experiments. It is a piece of glass cut laterally in three plane faces, and the ends of which are also equal and parallel triangular faces. The three right lines which form the intersection of two faces of the prism are called the *edges*. The mass of glass thus cut may be turned about an axis parallel to its edges; and it is moreover mounted on a stand with a double joint, so that it can be placed in any position whatever.

Prisms produce a remarkable effect upon light which traverses them. First a deviation, and second a decomposition into various kinds of light. Although these effects are always simultaneous, we shall examine the first by itself; the second will be afterwards investigated under the head of *dispersion*.

321. **Path of rays in a prism.**—To trace the path of a luminous ray in passing through a prism, let us suppose this cut by a plane perpendicular to its edges, and let *mno* (fig. 237) be the section thus obtained. If we consider the path of a ray of light L*a* along this section and meeting the prism at *a*, this ray approaches the perpendicular to the surface *mn*, and takes the direction *ab*. But on emerging from the prism it is again broken in the same direction, being deflected from the perpendicular at the surface *mo*; for it passes

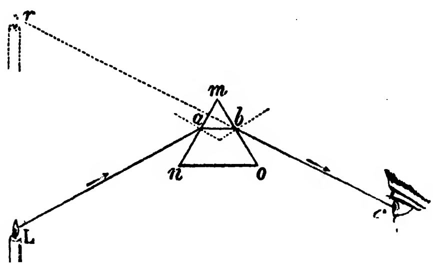

Fig. 237.

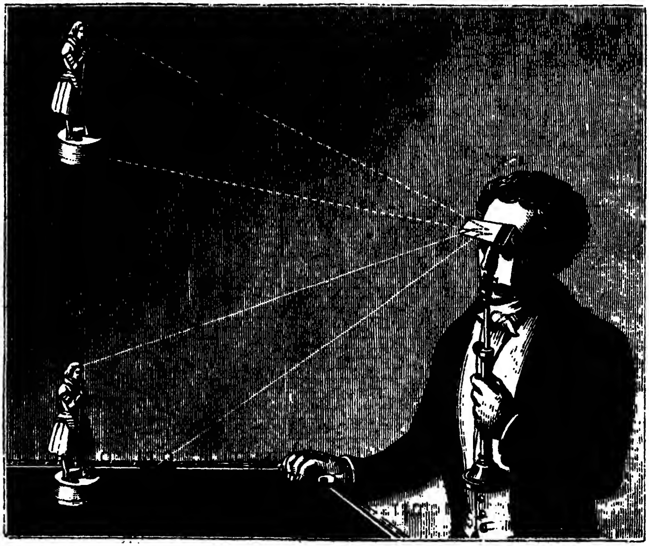

Fig. 238.

into a less refracting medium. It forms then a broken line,

$L abc$; so that the eye which receives the ray, bc, which is called the *emergent ray*, sees the object in the direction cbr; that is, raised towards the point m; which is expressed by saying that an object seen through a prism appears deflected towards the *summit;* that is, the edge which separates the face of incidence and convergence.

The phenomenon is very easily demonstrated by observing through a prism any object whatever, as represented in fig. 238. This is seen to be raised when the summit of the prism is uppermost, and lowered when the summit is downward. If the prism is vertical, the mage is displaced either to the right or to the left of the observer, according to the position of the summit in either direction.

This property which prisms have, of twice deflecting the light in the same direction, is the basis of all that has to be said about lenses.

LENSES.

322. **Different kinds of lenses.**—In optics the name *lens* is given to discs of glass bounded by two spherical surfaces, or by a plane and a spherical surface. The true lens, the only one to which the name is strictly applicable, is that in which both surfaces are bulged, such as is represented in a side view in fig. 239, and

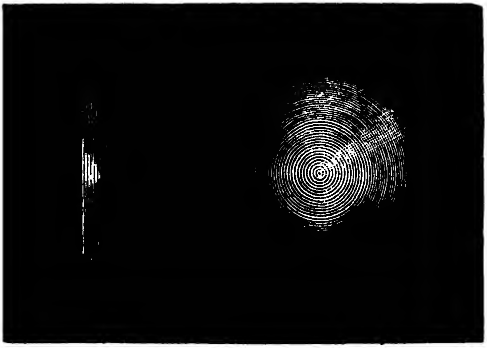

Fig. 239. Fig. 240.

in front in fig. 240; but this term of lens has been extended to other masses of glass, from the analogy of their action on light.

They are usually made either of *crown glass*, which is free from lead, or of *flint glass*, which contains lead, and is more refractive than crown glass.

The combination of spherical surfaces, either with each other

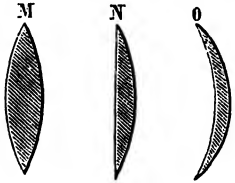

Fig. 241.

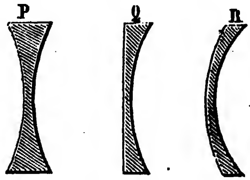

Fig. 242.

or with plane surfaces, gives rise to six kinds of lenses, sections of which are represented in figs. 241, 242; four are formed by two spherical surfaces, and two by a plane and a spherical surface.

M is a *double convex*, N is a *plano-convex*, O is a *converging concavo-convex*; P is a *double concave*, Q is a *plano-concave*, and R is a *diverging concavo-convex*. The lens O is also called the *converging meniscus*, and the lens R the *diverging meniscus*.

The first three, which are thicker at the centre than at the borders, are *converging*; the others, which are thinner in the centre, are *diverging*. In the first group, the double convex lens, M, only need be considered, and in the second the double concave, P, as the properties of each of these lenses apply to all those of the same group.

323. **Principal axis; optical centre; secondary axes.**—Before describing the properties of double convex lenses, we must premise

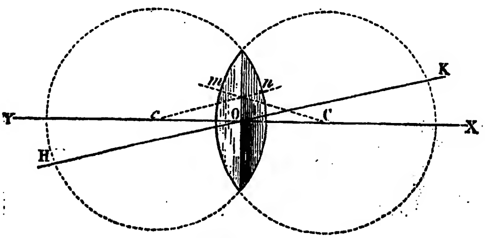

Fig. 243.

some definitions analogous to those already given for mirrors. We may remark that a double convex lens is, as shown in fig. 243, the

portion common to two spheres, which intersect each other. That being premised, the centres C and *c* of these spheres are called the *centres of curvature* of the lens, and the straight line, XY, which passes through these points, is the *principal axis*.

Besides these two centres of curvature, there is a remarkable point in the lenses, called the *optical centre*. This name is given to a point O, on the principal axis, equidistant from the two faces of the lens; at all events, when they have the same curvatures, which is the usual case. Now it can be shown by geometrical considerations, that any ray of light which passes through the optical centre, emerges without deflection; that is, it comports itself just as if it traversed a medium with parallel faces (319), while the luminous rays which do not pass through this point are deflected twice in the same direction, as in passing through prisms (321).

Any straight line, KH, which passes through the optical centre, without passing through the centres of curvature, is a *secondary axis*. There is only one principal axis, but the number of secondary axes is unlimited. We shall subsequently learn that the principal and the secondary axes play exactly the same part in the formation of images in lenses, as they do in concave or convex mirrors.

In order to compare the path of a luminous ray in a lens with that in a prism, the same hypothesis is made as for curved mirrors (305), that is, the surfaces of these lenses are supposed to be formed of an infinity of small plane surfaces or elements; the *normal* at any point is then the perpendicular to the plane of the corresponding element: at *m*, for instance, it is the straight line in C joining the points *m* to the centre of curvature; in like manner at *n* the normal is *cn*. This being premised, the properties of lenses are easily deduced from those of prisms (321).

324. **Path of rays in double convex lenses. Foci.**—The rays of light which traverse a lens may be either parallel or divergent; we will first consider the former case, and suppose further that the rays are parallel to the principal axis, as shown in fig. 244. Arguing on the above hypothesis, that the curved surface of a lens is an assemblage of small plane facettes, or elements inclined towards each other, it will be seen that the ray X, which coincides with the principal axis, traverses the lens perpendicularly to the facettes on entrance and emergence; and that, therefore, it continues to travel in a right line as traversing in reality a medium with parallel faces. This, however, is not the case with any other ray, L, more or less

distant from the principal axes; for here the small facettes at the points of incidence and emergence, being inclined to each other like

Fig. 244.

the aces of a prism, the ray is twice bent in the same direction, so as to cut the principal axis in a point F. Any other ray, M, is deflected in the same manner, and although more distant from the principal axis will cut it at F; which arises from the fact, that the two opposite facettes at the points of entrance and emergence, being the more inclined to one another the nearer they are to the edges of the lens, impart to the ray a greater deviation. All rays parallel to the axis behave in the same manner after having traversed the lens, and it can thus be understood how a parallel pencil is transformed into a converging pencil. The point where all the rays which were parallel to the axis coincide is called, as in the case of mirrors, the *principal focus*, and we shall represent it by the letter F. It may be formed on either side of the lens according to the direction in which light is propagated.

The position of the principal focus is fixed and is easy to determine; nothing more is required than to receive on the lens a pencil of parallel rays, a pencil of solar light for instance, and then to hold behind the lens a sheet of white paper. By moving this a position is found in which the luminous circle formed on the screen attains its maximum lustre: this point is the principal focus.

325. **Conjugate focus.**—We will now consider the case in which the source of light is at a small distance, but yet further than the principal focus (fig. 245). The pencil which is incident upon the lens being then divergent, it follows that, after having traversed the lens, the rays converge less rapidly than in fig. 244, and that, therefore, they no longer coincide in F, but beyond, in a point *l*, which is called the conjugate focus of the point L, to express, as in concave mirrors, the correlation of these two points; which is of

such a kind that, when the luminous object passes from L to *l*, the conjugate focus conversely passes from *l* to L.

The position of the conjugate focus is not fixed; it varies with that of the luminous object: the nearer this is to the lens the more distant is the conjugate focus, as shown by comparing fig. 246 with fig. 245; in fact, the incident rays being more and more diverging, the emergent rays are necessarily so too.

We will now consider the case in which the luminous object coming continually nearer the lens, ultimately coincides with the

Fig. 245

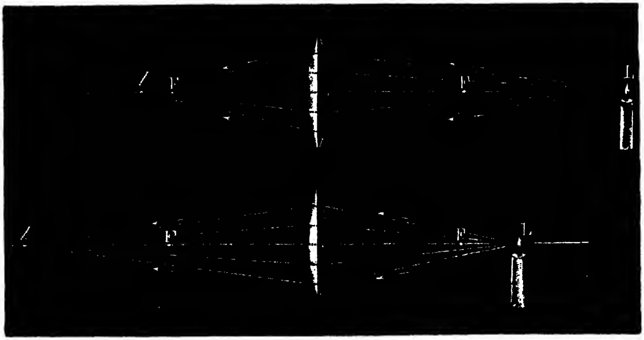

Fig. 246.

principal focus (fig. 247). This being the point where rays parallel to the axis coincide, it follows, conversely, that luminous rays, which emanate from this point, pursue in the opposite direction the same path as in arriving; that is to say, that they form on emerging from the lens a pencil parallel to the axis, and that in the present case no focus can be produced at any distance.

326. **Virtual focus.**—We have still to consider another focus, the *virtual focus.* Let us suppose a luminous object continually coming nearer the lens, ultimately comes between it and the principal focus (fig. 248). The divergence of the incident pencil being then greater than in fig. 247, it follows that the rays after emergence will be more and more spread out than in this figure: they should, therefore, become divergent, as shown in the pencil MN. The eye which receives these rays will suppose that they proceed from the point *l*, where their prolongations coincide. In this point the

luminous object will appear; it is not however a virtual focus, but only an optical illusion, just like that in a concave mirror, when the luminous object is placed between the mirror and its principal focus.

327. **Summary of properties of double convex lenses.**—We may deduce the three following principles as to the properties of double convex lenses from what has been said.

I. Luminous rays parallel to the axis, after having traversed a double concave lens, coincide in a single point which is the principal focus (fig. 244); and conversely rays from this focus form, on their emergence from the lens, a pencil parallel to the axis (fig. 247).

Fig 247.

Fig. 248.

II. Luminous rays emitted from a point outside the principal focus emerge convergent from the lens, and coincide in a point called the conjugate focus (fig. 245), which is formed at a greater distance behind the lens, the nearer is the luminous object to the principal focus.

III. Finally, the rays from a point between the lens and the principal focus emerge divergent, and give rise to a virtual focus on the same side as the object (fig. 248).

These ideas in reference to foci are indispensable in the explanation of the formation of images by lenses.

FORMATION OF IMAGES IN LENSES.

328. **Real images in double convex lenses.**—The refraction of light in double convex lenses gives rise to images, which are quite comparable to those seen by reflection in concave mirrors (309), and which like these are of two kinds, *real* and *virtual.*

We will first consider the case of the real image. This is formed whenever any object is placed in front of a condensing lens outside its principal focus; the lens reproduces then on the other side a reversed image of the object, which may be caught upon a screen (fig. 249), and is not less remarkable for the fidelity of the colour than for the accuracy of the outline; this is the real image. Its formation may be readily understood by reference to

Fig. 249.

what has been said about conjugate foci (325). Yet it must be added, that as all the properties of the principal axis apply exactly to the secondary axes, it follows that as a point on the principal axis has always its focus on this axis, so also any point on the secondary axis has its focus on the latter. Hence, in the above figure, all rays from the point A converge at *a* on the secondary axis through this point, and form the conjugate focus of this point, that is to say, its image. In like manner, the image of the point B forms at *b*, and as the same is the case for all points of the object, the result is a series of conjugate foci; these in their entirety constitute the image *ab*, which is inverted and smaller: the reversal arises from the crossing of the secondary axes between

the object and the image, and its smallness from its being formed nearer the lens than the object is.

Yet the image is not always smaller than the object; it may be greater. For, from the reciprocity of position between the object and its conjugate focus (325), if, in fig. 249, *ab* were the object, then as the luminous rays pursue the same path, but in the opposite direction, the image would be formed at AB, reversed as before, but larger. A double convex lens may thus give real images, which are either smaller or larger than the object. This may be

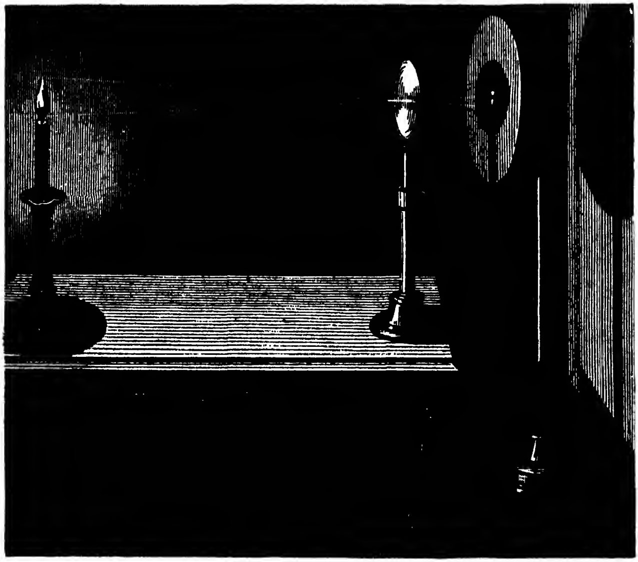

Fig. 250.

verified by the following experiment: in a dark room a double convex lens is placed, and in front of it, but some yards beyond the principal focus, a lighted candle. If then there is placed behind the lens a screen, which can be placed more or less near, a position is found in which there is produced on the screen a very small and inverted image of the candle, as shown in fig. 250. If, on the contrary, the lens be brought nearer the candle, and at the

same time the distance of the screen be increased, a reversed image is obtained, but it is greatly amplified (fig. 251).

This principle, that *double convex lenses give real and very small images of distant objects*, and, on the contrary, *greatly magnified images of near objects*, will meet with numerous applications in the optical instruments, which will be presently described, such as the microscope, the telescope, magic lantern, phantasmagoria.

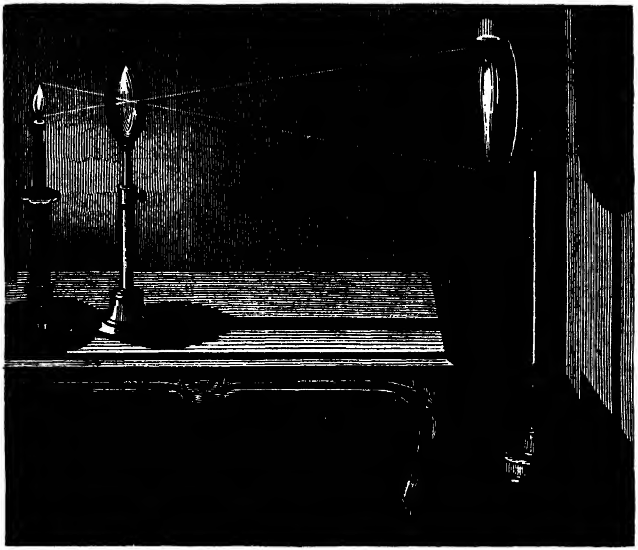

Fig. 251.

329. **Virtual images in double convex lenses.**—Besides the real images we have just considered, double convex lenses give also virtual images, which are produced under the same conditions as the virtual foci; that is, when the object is between the lens and the principal focus. For let an object, *ab*, be placed between a double convex lens and its principal focus: applying here what was previously said in reference to virtual foci, we know that all rays proceeding from any point, *a*, of the object emerge while diverging, and reach the eye as if they proceeded from the point A, where

the prolongation of the same rays coincide, and where there is formed for the eye the virtual image of the point *a*. For the same reason the eye sees at B the image of *b*; hence the image of AB appears at *ab*, but it is virtual; that is to say, it does not really exist, it could not be received on a screen, and is only an optical illusion.

It is to be remarked that in opposition to what takes place when

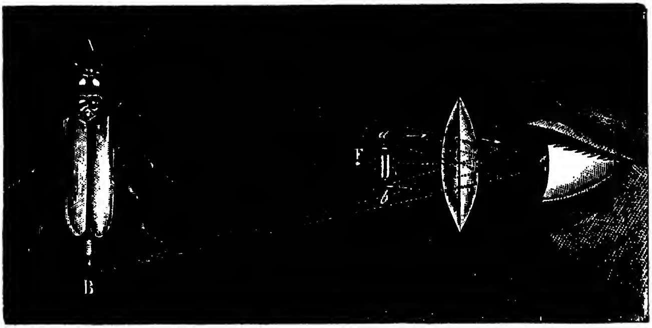

Fig. 252.

the image is real, the virtual image is erect, and in all cases larger than the object; the rectification of the image arises from the fact, that the secondary axes do not intersect between the image and the object, but beyond it; the magnification arises from the image being further than the object from the point of intersection of the secondary axes which pass through *a* and *b*.

The term lens is applied to the lenticular glasses used as magnifying glasses. Everyone is aware, that if the print of a book be closely looked at through such a lens it will appear larger; if the lens be progressively removed, a moment is reached when the characters disappear. This is the case when they are in the principal focus: when it is still further removed the characters reappear; but they are reversed, for then they are beyond the principal focus.

330. **Double concave lenses; foci and images.**—We have seen, in speaking about double convex lenses, that as the thickness decreases from the centre towards the edges, the small plane facettes, corresponding to the incidence and convergence of the same ray, are more and more inclined from the centre to the periphery.

But in double concave lenses, on the contrary, where the thickness increases from the centre to the edge, the small facettes are more

Fig. 253.

and more apart; and hence the opposite phenomena. For, while double convex lenses cause the rays traversing them to coincide, by breaking them twice in the same direction, so as to bring them nearer the principal axis, double concave lenses produce the opposite effect, and only increase the divergence of the rays.

This phenomenon may be readily understood by reference to

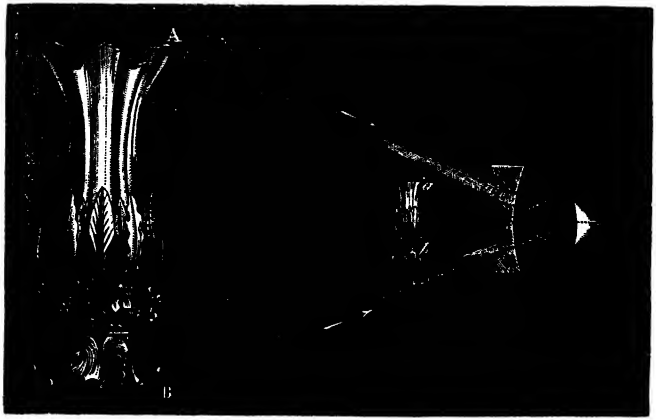

Fig. 254.

fig. 253, in which it is apparent how the rays are twice broken in the same direction, so as to diverge from the axis, and give rise to the diverging pencil MN. But the eye which receives this pencil

is acted upon by it, as if the luminous object were at *l*; there is thus produced a virtual focus, the only one possible in double concave lenses.

As these kinds of lenses have only virtual foci, they can produce none but virtual images; these images are moreover always erect and smaller than the object. Thus let AB be an object seen through a double concave lens (fig. 254); the luminous pencil from A is deflected on passing through the lens in such a manner as to reach the eye as if it were emitted from a point, *a*, on the secondary axis, AO. In like manner, the pencil from the point, B, reaches the eye as if it started from the point, *b*. There is formed therefore at *ab*, between the secondary axes, AO and BO, a virtual image of the object, AB, which is smaller and erect. This image is necessarily always smaller than the object, for it is nearer the point, O, where the secondary axes intersect.

APPLICATION OF LENSES.

331. **Refraction of heat.**—When a pencil of solar light is received on a condensing lens, not merely is light concentrated on its focus, but heat also; for if a piece of an inflammable substance, such as amadou, paper, cloth, wood, be placed in the focus, th

Fig. 255.

body soon begins to burn. With lenses of large diameter metals even may be melted.

This property which condensing lenses have is utilised for producing fire in what are called *burning glasses.* They may be a source of danger, by becoming a source of fire, when a lens is exposed to the solar rays. The same accident may be produced by spherical glass vessels; for they refract the light and heat like double convex lenses.

The concentration of the heat rays of the sun has received an application in certain solar dials, when the hour of midday is marked by the discharge of a small cannon (fig. 255). Above the cannon is a condensing lens, the focus of which exactly corresponds to the *touch-hole* of the cannon the moment the sun passes the meridian of this place. Hence, the cannon being charged and primed beforehand, the lens ignites the powder just at midday, and the explosion announces the time at a distance.

Yet the time thus given is what is called in astronomy *solar time*, or *true time*, in which the length of day varies. Now our watches and clocks being regulated for *mean time*, that is to say, for an unchangeable day, only agree with the sun four times a year; December 24, April 15, June 15, and September 1. On February 11 a clock giving mean time is 14′ 37″ faster than the sun, and on November 3 it is 16′ 17″ slow. The *equation of time* represents the amount which on all the days of the year must be added to or taken from the time of a clock to obtain the mean time. Hence it is incorrect to use the ordinary expression, that a good watch or a good clock goes like the sun.

332. **Beacons. Lighthouses.**—These are fires lighted at night on high towers along the shores of the sea, in order to guide mariners in darkness and enable them to keep clear of danger.

Beacon fires were originally wood or coal fires; but these were dull and unsteady. They were afterwards replaced by oil lamps placed in the principal focus of concave reflectors, which sent the reflected light to a great distance, for its rays were parallel.

In 1822 Fresnel made a great improvement in the illumination of *lighthouses* as they are now called. Abandoning the use of metallic reflectors, which soon tarnished under the influence of the sea-fogs, Fresnel substituted large plano-convex lenses, in the focus of which he placed a powerful lamp with four concentric wicks, and equal in illuminating power and quantity of oil consumed to seventeen Carcel lamps. But the difficulty of constructing such lenses, which must necessarily be large, and at the same time not thick, so as not to absorb much light, led Fresnel to

adopt a special system of lenses, known as *echelon* or *lighthouse lenses.*

Seen in front in fig. 256, and in profile in fig. 257, they consist of a plano-convex lens, A, a foot in diameter, round which are arranged eight or ten glass rings, which are also plano-convex, and whose curvature is calculated, so that each has the same focus as the central lens, A. A lamp being placed in the focus of this refracting system, an immense horizontal pencil, RC, is formed, which sends the light to a great distance. Further, above and below these lenses, are placed several silvered glass mirrors, *mn.*

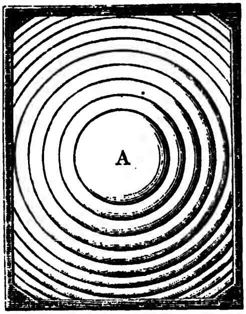

Fig. 256

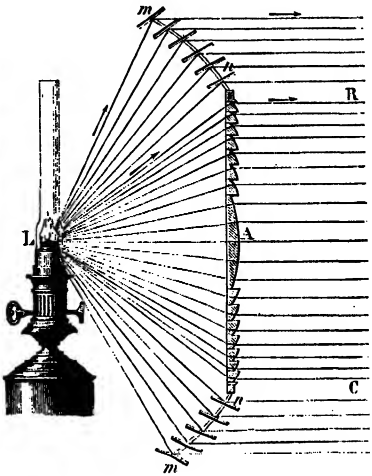

Fig. 257.

Thus the rays, which would be lost towards the sky and the earth, are utilised and sent in a horizontal direction. By this double combination a vast horizontal pencil is obtained, which sends the light of the lamp to a distance of 20 or 30 miles; but it only sends it in one direction. To increase the number of points of the horizon at which the light can be seen, Fresnel, instead of a single system of lenses and mirrors represented in fig. 257, united eight such arrangements, so as to form an enormous glass pyramid with eight faces, as seen in fig. 258, which represents a lighthouse lens of the largest size, constructed by M. Soutter, and exhibited at the

Paris Universal Exhibition in 1855. The system of mirrors and lenses alone is 10 feet high.

A lighthouse lens of this kind sends a powerful beam of light towards eight points of the horizon, but all other points are desti-

Fig. 258.

tute of light, so that vessels sailing in these dark parts would have no help from the lighthouse. This difficulty was removed by Fresnel by means of a very simple mechanism, represented at the lower part of fig. 258. A clockwork motion, M, moved by a weight, P, imparts to the whole system of lenses, AB, a slow rotating motion on six rollers. During a complete revolution of the apparatus, the

whole horizon is successively illuminated, and the mariner lost in the night sees the light alternately appear and disappear after equal intervals of time. These alternations serve to distinguish lighthouses from an accidental fire or a star. By means too of the number of times the light disappears in a given time, and by the

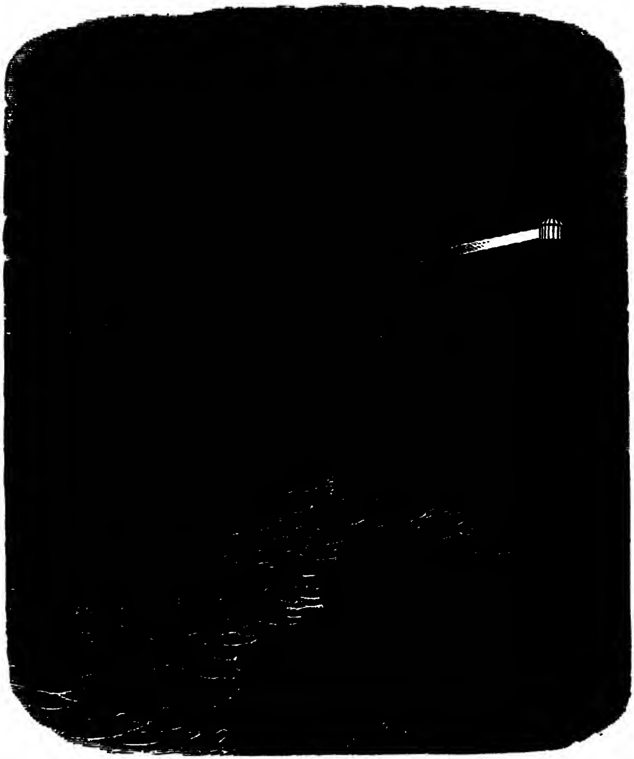

Fig. 259.

colour of the light, sailors are enabled to distinguish the lighthouses from one another, and hence to know their position.

Of late years the use of the electric light has been substituted for that of oil lamps; a description of the apparatus will be given in a subsequent chapter.

CHAPTER V.

DECOMPOSITION OF LIGHT BY PRISMS.

333. **Solar spectrum.**—In speaking of prisms and lenses, we have only considered the change in direction which these transparent media impart to luminous rays, and the images which result therefrom; but the phenomenon of refraction is by no means so simple as we have hitherto assumed: when *white* light, or that which reaches us from the sun, passes from one medium into another, *it is decomposed into several kinds of lights*, a phenomenon to which the name *dispersion* is given.

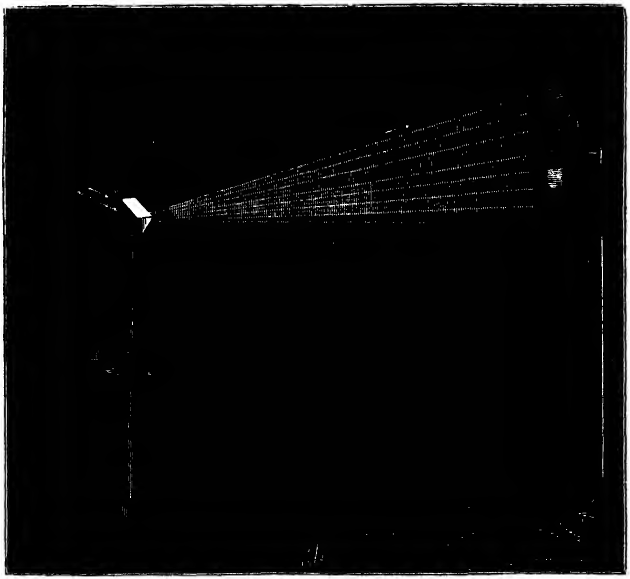

Fig. 26c.

In order to show that white light is decomposed by refraction, a pencil of solar light, SA (fig. 260), is allowed to pass through a

small aperture in the window shutter of a dark chamber. This pencil tends to form a round and colourless image of the sun at K; but if a flint glass prism arranged horizontally be interposed in its passage, the beam, on emerging from the prism, becomes refracted towards its base, and produces on a distant screen a vertical band, coloured in all the tints of the rainbow, which is called the *solar spectrum.* In this spectrum, the production of which forms one of the most brilliant optical experiments, there is, in reality, an infinity of different tints, which imperceptibly merge into each other; but with Newton, it is customary to distinguish seven principal colours, as seen in the adjoined coloured plate. These are *violet, indigo, blue, green, yellow, orange, red*: they are arranged in this order in the spectrum, the violet being the most refrangible, and the red the least so. They do not all occupy an equal extent in the spectrum, violet having the greatest extent, and orange the least.

From the experiment of the solar spectrum, Newton concluded that *white* light, that is, light coming from the sun, is not homogeneous, is not simple; but consists of seven different lights, which, united, give the impression of white, while, when separated, each produces its own colour. He ascribed the separation of these seven lights on their passage through the prism to their different degrees of refrangibility. For if they were all equally refrangible, as they would be equally bent on entering and emerging from the prism, they would traverse it without being separated, and the light would be white on emerging as well as on incidence.

334. **The colours of the spectrum are simple.**—If one of the colours of the spectrum (the yellow, for instance) be isolated by intercepting the others by means of a screen, and if the light thus intercepted be allowed to pass through a second prism, it is deflected, but without decomposition; that is, it only gives rise to a single emergent pencil. As the same phenomenon is observed with the other colours of the spectrum, it is concluded that they are indecomposable by the prism, which is expressed by saying that the seven colours of the spectrum are *simple* or *primitive colours.*

As regards the cause, in virtue of which one part of the spectrum produces on us the sensation of red, another of yellow, another of orange, and so forth, the undulatory theory teaches us that it depends upon the number of vibrations performed by the molecules of ether. This number, which is very great, differs with each colour, and increases from red to violet. Fresnel has calculated that for the

extreme red it is 458 millions of millions in a second, and for violet 727 millions of millions. As the velocity of propagation is the same for all the colours of the spectrum, but each corresponds to an unequal number of vibrations, it follows that the length of these vibrations must vary with different colours. It has been calculated that, in the case of red, the length of the vibration is 620 millionths of a millimeter, and for violet 425 millionths.

335. **Luminous, calorific, and chemical effects of the spectrum.**—The various spectral rays differ not only in their colour, but also in their luminous power, in the heat by which they are accompanied, and by the chemical effects to which they give rise. It is found that the middle pencils, the yellow and the green, illuminate the most powerfully. Thus the print of a book placed in the yellow pencil is seen more distinctly than in the red or violet.

The calorific action of the spectrum is demonstrated by successively placing a very delicate thermometer in the various parts of the spectrum. It is observed that in the red, or even a little beyond it, the heat attains its greatest intensity. This proves the existence of invisible heat rays, which are less refrangible than all other spectral rays.

Passing from the calorific action of light to its chemical action, we may first observe that it tends to destroy most vegetable colours, such as wall papers and dyed stuffs, which rapidly fade if exposed to bright light. Some chemical substances are known which are naturally white, and are blackened by the luminous rays : there are gaseous mixtures, also, which suddenly explode when exposed to the sun's rays. These chemical effects are not produced equally in all parts of the spectrum; the greatest chemical action is met with in the violet, and even a little beyond.

We may thus say that the heating effect is met with in the extreme red, the luminous in the yellow, and the chemical action in the extreme violet.

336. **Dark lines of the spectrum.**—The colours of the solar spectrum are not perfectly continuous : throughout the whole extent of the spectrum are a great number of very narrow dark lines. They are best observed by admitting a pencil of solar rays into a darkened room through a narrow slit. If at a distance of three or four yards we look at this slit through a flint glass prism, with its edge held parallel to the edge of the slit, we observe a number of very delicate dark lines parallel to the edge of the prism, and at very unequal intervals.

The existence of these dark lines was first observed by Wollaston in 1802; but Fraunhofer, a celebrated optician of Munich, first studied and gave a detailed description of them. He mapped the lines, and denoted the most marked of them by the letters A, *a*, B, C, D, E, *b*, F, G, H; they are therefore generally known as *Fraunhofer's lines*.

The dark line A (see fig. 1 of the coloured plate) is towards the end, and B in the middle of the red ray; C is in the red but rather nearer the orange ray; D is in the orange ray, E in the yellow, F in the transition from green to blue, G in the indigo, H in the violet. There are certain other noticeable dark lines, such as *a* in the red, and *b* in the green. In the case of solar light the positions of the dark lines are fixed and definite; in the spectra of artificial lights and of the fixed stars the relative positions of the dark lines vary. For the electric light there are bright lines instead of dark arcs; and in coloured flames, that is to say, flames in which certain chemical substances undergo evaporation, the dark lines are replaced by very brilliant lines of light, which differ with different substances.

337. **Spectrum analysis.**—This property of coloured flames was first discovered by Sir John Herschell, who remarked that by volatilising substances in a flame a very delicate means is afforded of detecting certain ingredients by the colours they impart to certain of the dark lines of the spectrum; and Fox Talbot, in 1834, suggested optical analysis as probably the most delicate means of detecting minute portions of a substance. To Kirchhoff and Bunsen, however, is really due a method of basing on the observation of these lines a method of analysis. They ascertained that salts of the same metal, when introduced into a flame, always produce the lines identical in colour and position, but different in colour, position, or number, for different metals; and, finally, that an exceedingly small quantity of a metal suffices to disclose its existence. Hence has arisen a new method of analysis known as *spectrum analysis*.

338. **Spectroscope.**—The name *spectroscope* has been given to the apparatus used by Kirchhoff and Bunsen for the study of the spectrum. One of the forms of this apparatus is represented in fig. 261. It consists of three telescopes mounted on a common foot, and whose axes converge towards a prism, F, of flint glass. The telescope A is the one through which the spectrum is observed; it is *focussed* by means of the milled head-screw *m*. The telescope B has a slit the width of which can be regulated by the screw *v*.

K is what is known as a *Bunsen's burner*, in which coal gas is burned, mixed with air in such a manner that a flame of little or no

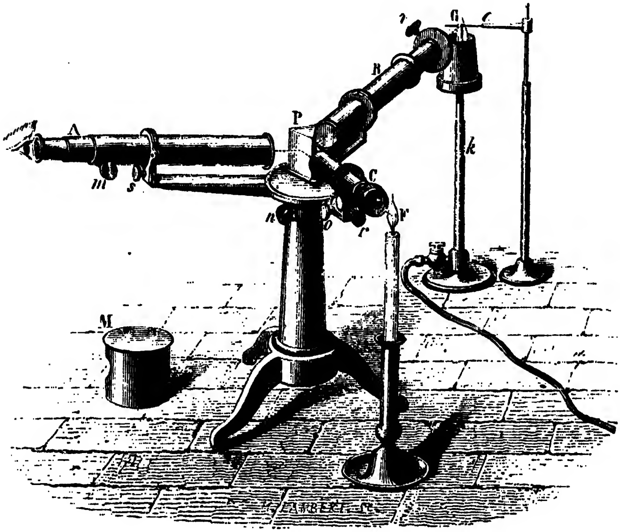

Fig. 261.

luminosity, but of intense heat, is produced. The substance to be examined is placed in this, either in the solid form, or in a state of solution on the platinum wire at the end of the support, *c*. It is thus volatilised by the intense heat, and the flame G is coloured. The rays emitted from this flame pass through the slit and through a system of lenses, so that on emerging they form a parallel pencil of rays which falls on the prism P. Here they are refracted and decomposed and form the prismatic spectrum. The spectator, on looking through the telescope A, sees a real and inverted image of the spectrum.

The telescope C has a different function; it contains a micrometric scale photographed on glass, so that it is white on a dark ground. The light from the candle passing through the scale and the lens in C falls in parallel rays *on the face* of the prism P, and is *reflected* from thence through the object-glass of A, so that the observer seeing the spectrum and the scale simultaneously can exactly

measure the relative distances of the various spectral lines. M is a metal cap with three apertures which covers the prism so as to exclude the diffused light.

339. **Experiments with the spectroscope.**—The adjacent coloured plate shows certain spectra observed by means of the spectroscope. Fig. I. represents the solar spectrum.

Fig. II. shows the spectrum of potassium. It is *continuous*; that is, it contains all the colours of the solar spectrum; moreover, it is marked by two brilliant lines, one in the extreme red, corresponding to Fraunhofer's dark line, A; the other in the extreme violet.

Fig. III. shows the spectrum of sodium. This spectrum contains neither red, orange, green, blue, nor violet. It is marked by a very brilliant yellow ray in exactly the same position as Fraunhofer's dark line D. Of all metals sodium is that which possesses the greatest spectral sensibility. In fact, it has been ascertained that one two hundred millionths of a grain of soda is enough to cause the appearance of the yellow line of sodium. Consequently it is very difficult to avoid the appearance of this line. A very little dust scattered in the apartment is enough to produce it,—a circumstance which shows how abundantly sodium is scattered throughout nature.

Figs. IV. and V. show the spectra of *cæsium* and *rubidium*, metals discovered by MM. Bunsen and Kirchhoff by means of spectral analysis. The former is distinguished by two blue lines, the latter by two very brilliant red lines and by two less intense violet lines. A third metal, *thallium*, has been discovered by the same method by Mr. Crookes in England, and independently by M. Lamy in France. Thallium is characterised by a single green line.

Still more recently Richter and Reich have discovered a new metal associated, with zinc, and which they call *indium*, from a couple of characteristic lines which it forms in the indigo.

The extreme delicacy of the spectrum reactions, and the ease with which they are produced, constitute them a most valuable help in the quantitative analysis of the alkalies and alkaline earths. It is sufficient to place a small portion of the substance under examination on platinum wire as represented in fig. 261, and compare the spectrum thus obtained either directly with that of another substance, or with the charts in which the positions of the lines produced by the various metals are laid down.

With other metals the production of their spectrum is more difficult, especially in the case of some of their compounds. The

heat of a Bunsen's burner is insufficient to vaporise the metals, and a more intense temperature must be used. This is effected by taking electric sparks between wires consisting of the metal whose spectrum is required, and the electric sparks are most conveniently obtained by means of Ruhmkorff's coil. Thus all the metals may be brought within the sphere of spectrum observations.

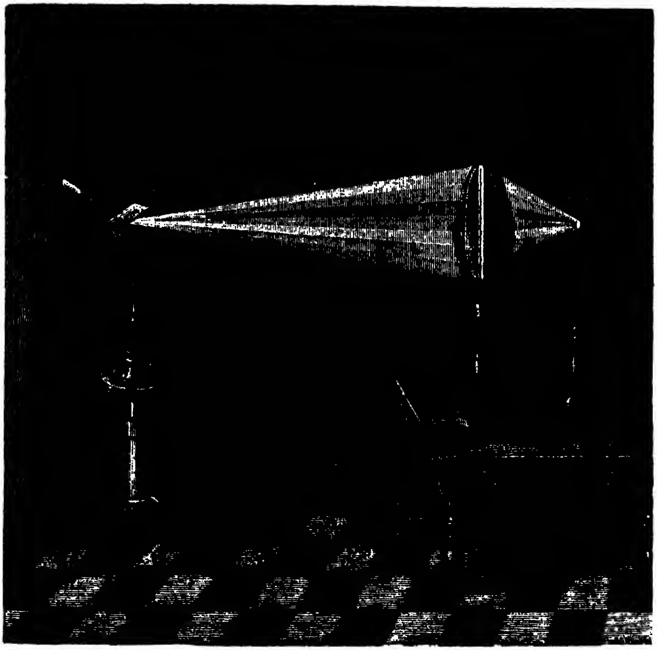

Fig. 262.

340. **Recomposition of white light.**—Not merely can white light be resolved into lights of various colours, but by combining the different pencils separated by the prism, white light can be reproduced. This may be effected in various ways :

I. A pencil of solar light is decomposed by a prism, as shown in fig. 262, and the spectrum is caught, not on a screen, but on a rather large double convex lens, in the focus of which is placed a small cardboard or ground glass and screen. The seven colours

of the spectrum coincide in the focus, and there is formed on the screen a perfectly white circular image, which shows that the union of the seven lights of the spectrum reproduces white light.

II. The same result is attained by replacing the double convex lens in the preceding experiment by a concave mirror. The seven coloured pencils being reflected from this mirror, there is formed in the focus the same white image as in the preceding experiment.

III. By means of Newton's disc it may be shown that the seven colours of the spectrum form white. This is a cardboard disc of

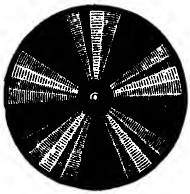

Fig. 263.

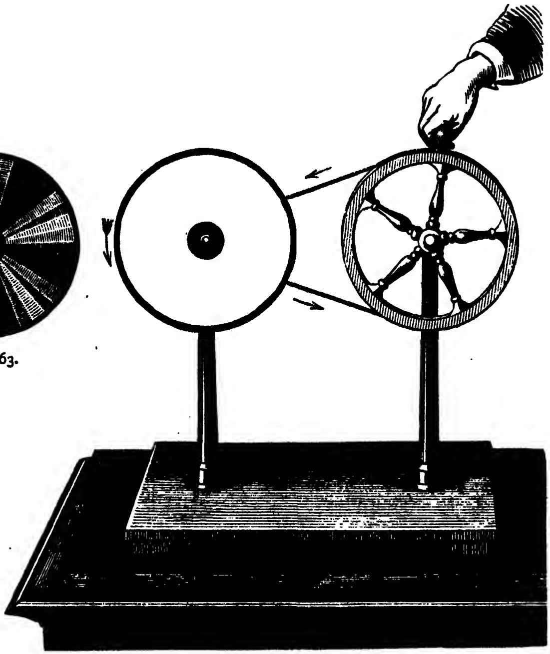

Fig. 264.

about a foot in diameter, the centre and the edges are covered with black paper, while in the space between there are pasted strips of papers of the colours of the spectrum. They proceed from the centre to the circumference, and their relative dimensions and tints are such as to represent five spectra (fig. 263). When this disc is

rapidly rotated, by means of the mechanism represented in fig. 264, it appears white, or at all events of a greyish-white, for the colours which cover it cannot be arranged exactly in the same dimensions or of the same tints as those of the spectrum.

To explain this phenomenon let us observe that the impression produced upon the eye by the sight of a luminous body lasts a certain time after the cause which produced it has ceased. Thus, if a lighted stick be rapidly turned round, a luminous ray is produced, which shows that the sensation produced upon the eye lasts after the stick has passed from in front of this body. Thus, too, in the above experiment, the disc is turned so rapidly that the action of the seven colours is simultaneous, and the eye is affected as if it received them all together, and the disc therefore appears white.

341. **Newton's theory of the composition of light and the colour of bodies.**—Newton was the first to decompose white light by the prism, and to recompose it. From the various experiments which we have described he concluded that white light was not homogeneous, but formed of seven lights unequally refrangible, which he called *simple* or *primitive* lights.

He was further led to the conclusion, that bodies are not of themselves coloured, have no colour of their own, but that they have the property of decomposing white light, which illuminates them, and of reflecting unequally the various kinds of light of which it is formed. Thus, vermilion is not red of itself, but is endowed with the property of reflecting red light and of absorbing all others, or at any rate of only reflecting them in far less proportion. In like manner the leaves of plants are not truly green; they have merely a greater reflecting power for green than for any other colour. In short, bodies are only coloured by the light they reflect. For, let these same green leaves be placed in a spectrum projected in a dark room, if they are in the green band they will appear of a dazzling green, far brighter than their natural colour; but if they are placed in the red they will appear red, and of violet if placed in violet. A similar effect is produced if a rose be successively placed in each of the spectral bands, showing that the colour of a body is not peculiar to them, but depends upon the kind of light which their molecular constitution gives them the power of reflecting. In speaking, too, of the *green* or the *red pencil*, we do not mean that they are coloured of themselves, but merely that they have the power of producing in us the sensation of red, or of yellow.

The eye judges colours as the ear judges sounds; both the colours and the sounds depend on the number of vibrations.

Bodies which reflect all colours in the spectrum equally well are white, those which reflect none at all are black; so that black is not really a colour, but the absence of colour.

The varied shades which coloured bodies present result not merely from the fact that they simultaneously reflect various kinds of light, but reflect them to different extents. Thus, a body which reflects yellow and blue light will be green, but a green the shade of which varies with the quantities of yellow and of blue light which the body reflects. Thus, if by means of an opaque screen, part or all of certain colours be intercepted, and the others be united by means of a lens, as shown in fig. 262, there is no shade in nature which cannot be reproduced, but with a lustre and richness of colour which artificial pigments can never attain.

342. **Colours of transparent bodies.**—We have seen above that opaque bodies owe their colour to the power of decomposing light by reflection, that is, of reflecting certain colours more abundantly than others. It is owing to the decomposition of light that transparent bodies seem to be coloured: though here the decomposition is effected by transmission and not by reflection. If all rays of the spectrum were equally transmissible by transparent media they would necessarily be colourless; that, however, is never quite the case, at all events when the media have a certain thickness; for then they absorb certain colours of the spectrum more than others, and have the tint of the more transmissible colour. Water, for instance, seen by transmission through a great thickness, has a greenish tint, which shows that of all colours contained in white light, it allows green to pass most easily.

Air, in great thickness, gives a bluish tint to distant objects, which would rather tend to prove that air is more transparent for blue than for any other spectrum colour. Yet, as it transmits solar light without alteration, the blue colour of the celestial vault ought rather to be attributed to the innumerable reflections which the diffused light sent in all directions by terrestrial objects undergoes at the molecules of the air.

343. **Complementary colours. Accidental images.**—If in white light any colour be suppressed, a mixture of the remainder is called the *complementary colour*, for it is the colour needed to complete the sensation of white light. A mixture of blue and yellow produces a *green*, and, accordingly, green is the comple-

mentary colour to red. In like manner, a mixture of red and yellow produces *orange*, which is complementary to blue. Similarly indigo is the complementary colour to yellow, and yellowish green to violet.

Effects of complementary colours are met with in many curious experiments. Thus, let any coloured object, a wafer for instance, be placed on a black ground, and let it be viewed for some minutes until the sight is fatigued; if then the eyes be turned to a sheet of white paper, an image will be seen of the same form as the object, but of the complementary colour; that is, that if the wafer is red its image will be green, if it is orange the image will be blue, and so forth. In like manner, if, after looking for some time at the setting sun, the eye be turned to a white wall, an intense green disc will be seen, which lasts for some minutes, after which the red image reappears; a second green image succeeds to it, and so on for a great number of times, until the appearance fades away.

These images which thus persist sometime after an object has been looked at, and which have the complementary colours of those of the object, were first observed by Buffon, who gave them the name of *accidental images*.

There is another kind of accidental colour also noticed by Buffon; when a colour object placed on a dark ground is attentively looked at for sometime the object is seen to be surrounded by a colour which is complementary to that of the object. This phenomenon, which is known as the *accidental halo*, is easily verified by means of a coloured wafer placed on a sheet of white paper.

When several pieces of cloth of the same colour are successively looked at it will be seen that the latter ones appear of a bad shade. This arises from the fact, that the accidental colour of the cloth begins to form, and its tint loses its brightness. So too when designs are printed, or cloth embroidered on a coloured ground, effects may be obtained quite different from those which were desired. Generally if two adjacent colours are complementary, each will acquire a greater lustre; but if they are of the same tint, they will mutually enfeeble each other. It will thus be seen how numerous are the applications which the phenomenon of accidental images presents in combining colours in pictures, wall papers, tapestry, furniture, even the toilet, although good taste has long been in advance of the data of science.

344. **Irradiation.**—This is a phenomenon in virtue of which white objects, or those of a very bright colour, when seen on a dark

ground, appear larger than they really are. With a black body on a bright ground, the converse is the case. Irradiation arises from the fact, that the impression produced on the retina extends beyond the outline of the image. It bears the same relation to the space occupied by the image that the duration of the impression does to the time during which the image is seen.

The effect of irradiation is very perceptible in the apparent magnitude of stars, which may thus appear much larger than they really are; also in the appearance of the moon when two or three days old, the brightly illuminated crescent seeming to extend beyond the darker portion of the disc, and hold it in its grasp.

Plateau, who has investigated this subject, finds that irradiation differs very much in different people, and even in the same person it differs on different days. He has also found that irradiation increases with the lustre of the object, and the length of time during which it is viewed. It manifests itself at all distances, diverging lenses increase it, condensing lenses diminish it.

345. **Rainbow.**—The *rainbow* is a luminous meteor which appears in the clouds opposite the sun when they are resolved into rain. It consists of seven concentric arcs, presenting successively the colours of the solar spectrum. Sometimes only a single bow is perceived, but there are usually two; a lower one, the colours of which are very bright, and an external or *secondary* one, which is paler, and in which the order of the colours is reversed. In the interior rainbow the red is the highest colour; in the other rainbow the violet is. It is seldom that three bows are seen; theoretically a greater number may exist, but their colours are so feeble that they are not perceptible.

The phenomenon of the rainbow is produced by the decomposition of the white light of the sun when it passes into the drops, and by its reflection from their inside face. In fact, the same phenomenon is witnessed in dewdrops and in jets of water; in short, wherever solar light passes into drops of water under a certain angle.

The appearance and the extent of the rainbow depend on the position of the observer, and on the height of the sun above the horizon; hence only some of the rays refracted by the rain-drops, and reflected in their concavity to the eye of the spectator, are adapted to produce the phenomenon. Those which do so are called *effective rays.*

To get a general idea of this let us refer to fig. 265, in which two

rain drops, *a* and *c*, are represented extremely magnified as compared with the arc of which they formed part. The pencil of white light which falls upon *a*, is refracted on entrance into the droplet and decomposed, giving rise to seven rays, red, orange, yellow, green, blue, indigo, and violet (333). At the point *a*, on the posterior face of this droplet, a portion of the refracted light escapes, and is dispersed in the atmosphere without giving rise to any particular phenomenon; the light which has not emerged from the droplet is collected at *a*, returns and emerges in being a second time refracted, and reaches the observer's eye as represented in the figure.

Fig. 265.

A second droplet, *c*, placed below the preceding one, produces just the same effect: yet it does not send the same colour to the spectator. For, as the different colours are unequally refrangible, the coloured rays which emerge from the same raindrop diverge, and, therefore, are not propagated together; whence it follows that each drop only sends one kind of colour towards the observer. But from the degree of refrangibility of each ray, the droplets on the outside of the arc send only red rays towards the eye, and those on the inside violet rays. The other colours arise from intermediate droplets.

In short, the rainbow is the circumference of the base of a cone, the apex of which is the observer's eye, and the surface of this cone is formed from the outside to the inside of seven successive enve-

lopes, red, orange, yellow, etc., corresponding to each of the bands of the spectrum. The nearer the sun is to the horizon the larger is the visible part of the rainbow; but, as the sun rises, the arc diminishes, and entirely disappears when the sun is 42 degrees above the horizon. Hence the rainbow is never seen except morning and evening.

CHAPTER VI.

INJURIOUS EFFECTS OF COLOUR IN LENSES. ACHROMATISM.

346. **Aberration of refrangibility.**—In speaking of lenses we have been quite silent about a grave objection to which they are liable, which is, that at a certain distance objects seen through these lenses seem surrounded by an iridescent fringe, which fatigues the sight and greatly injures the precision of the images.

For, as lenses may be compared to a series of prisms with infinitely small faces, and united at their bases, they not only refract light, but also decompose it like a prism. On account of this dispersion, therefore, lenses have really a distinct focus for each colour. In condensing lenses, for example, the red rays, which are the least refrangible, form their focus at a point *r* on the axis of the lens (fig. 265), while the violet rays, which are most refrangible, coincide in the nearest point, *v*. The foci of the orange, yellow, green, blue, and indigo, are between these points. Hence a double convex lens tends to give seven images unequally coloured of images seen through them. These images being partly superposed, the seven colours combine in the centre to form white light, but, on the contours, the extreme colours of the spectrum are visible, that is, more especially red and blue.

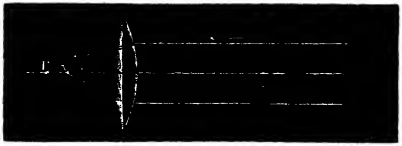

Fig. 266.

This injurious colouration of the images is called the *chromatic aberration.*

347. **Achromatic lenses.**—By observing the phenomenon of the dispersion of colours in prisms of water, of oil of turpentine, and of

crown-glass, Newton was led to suppose that dispersion was proportional to refraction. He concluded that there could be no refraction without dispersion, and, therefore, that achromatism was impossible. Almost half a century elapsed before this was found to be incorrect. Hall, an English philosopher, in 1733, was the first to construct achromatic lenses, but he did not publish his discovery. It is to Dollond, an optician in London, that we owe the greatest improvement which has been made in optical instruments. In 1757 he combined two lenses, one a double convex *crown-glass* lens, the other a double concave lens of *flint-glass* (fig. 267), a kind of glass which contains a good deal of lead, and which has greater dispersive power than flint-glass.

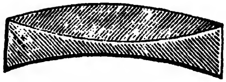

Fig. 267.

By suitably choosing the curvatures of these two lenses, they may become unequally dispersive, and as the dispersion is in opposite directions, one of the lenses being convergent and the other divergent, two effects are produced, which compensate each other as regards colouration, but not as concerns refraction; that is, a ray of white light which has traversed such a lens emerges colourless, but converging, and forming a single focus on the axis.

The lenses thus formed of flint and crown-glass give images which are not coloured on the edges; they have hence been called *achromatic* lenses; *achromatism* being the term applied to the phenomenon of the refraction of light without decomposition.

348. **Spherical aberration.**—Chromatic aberration is not the only defect which lenses present: they have another, which is known as *spherical aberration*, and which arises from the fact, that, apart from dispersion, the rays which traverse a condensing lens do not exactly coincide in a single focus. Those which traverse the lens near the edges are too much refracted as compared with those which traverse the central part; hence the former rays converge nearer to the lens than do the latter, in consequence of which the images are distorted.

This inconvenience is obviated in optical instruments by intercepting the rays which traverse the lens near the edge by *diaphragms* or *stops*, perforated by circular holes, which only allow the central rays to pass.

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INJURIOUS EFFECTS OF COLOUR IN LENSES. ACHROMATISM.

346. **Aberration of refrangibility.**—In speaking of lenses we have been quite silent about a grave objection to which they are liable, which is, that at a certain distance objects seen through these lenses seem surrounded by an iridescent fringe, which fatigues the sight and greatly injures the precision of the images.

For, as lenses may be compared to a series of prisms with infinitely small faces, and united at their bases, they not only refract light, but also decompose it like a prism. On account of this dispersion, therefore, lenses have really a distinct focus for each colour. In condensing lenses, for example, the red rays, which are the least refrangible, form their focus at a point *r* on the axis of the lens (fig. 266), while the violet rays, which are most refrangible, coincide in the nearest point, *v*. The foci of the orange, yellow, green, blue, and indigo, are between these points. Hence a double convex lens tends to give seven images unequally coloured of images seen through them. These images being partly superposed, the seven colours combine in the centre to form white light, but, on the contours, the extreme colours of the spectrum are visible, that is, more especially red and blue.

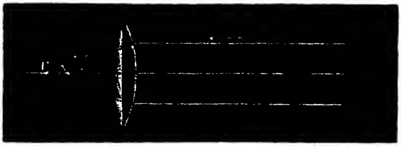

Fig. 266.

This injurious colouration of the images is called the *chromatic aberration.*

347. **Achromatic lenses.**—By observing the phenomenon of the dispersion of colours in prisms of water, of oil of turpentine, and of

crown-glass, Newton was led to suppose that dispersion was proportional to refraction. He concluded that there could be no refraction without dispersion, and, therefore, that achromatism was impossible. Almost half a century elapsed before this was found to be incorrect. Hall, an English philosopher, in 1733, was the first to construct achromatic lenses, but he did not publish his discovery. It is to Dollond, an optician in London, that we owe the greatest improvement which has been made in optical instruments. In 1757 he combined two lenses, one a double convex *crown-glass* lens, the other a double concave lens of *flint-glass* (fig. 267), a kind of glass which contains a good deal of lead, and which has greater dispersive power than flint-glass.

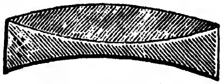

Fig. 267.

By suitably choosing the curvatures of these two lenses, they may become unequally dispersive, and as the dispersion is in opposite directions, one of the lenses being convergent and the other divergent, two effects are produced, which compensate each other as regards colouration, but not as concerns refraction; that is, a ray of white light which has traversed such a lens emerges colourless, but converging, and forming a single focus on the axis.

The lenses thus formed of flint and crown-glass give images which are not coloured on the edges; they have hence been called *achromatic* lenses; *achromatism* being the term applied to the phenomenon of the refraction of light without decomposition.

348. **Spherical aberration.**—Chromatic aberration is not the only defect which lenses present: they have another, which is known as *spherical aberration*, and which arises from the fact, that, apart from dispersion, the rays which traverse a condensing lens do not exactly coincide in a single focus. Those which traverse the lens near the edges are too much refracted as compared with those which traverse the central part; hence the former rays converge nearer to the lens than do the latter, in consequence of which the images are distorted.

This inconvenience is obviated in optical instruments by intercepting the rays which traverse the lens near the edge by *diaphragms* or *stops*, perforated by circular holes, which only allow the central rays to pass.

CHAPTER VII.

OPTICAL INSTRUMENTS.

349. **The different kinds of optical instruments.**—By the term *optical instrument* is meant any combination of lenses, or of lenses and mirrors. By their means the limits of vision have been enormously increased, and the most favourable influence has been exerted on the progress of science, by opening out new worlds to investigation which would otherwise have remained unknown. Optical instruments may be divided into three classes according to the ends they are intended to answer, viz. :—i. *Microscopes*, which are designed to obtain a magnified image of any object whose real dimensions are too small to admit of its being seen distinctly by the naked eye. ii. *Telescopes*, by which very distant objects, whether celestial or terrestrial, may be observed. iii. *Instruments* designed to project on a screen a magnified or diminished image of any object which can thereby be either depicted or rendered visible to a crowd of spectators; such as the *camera lucida*, the *camera obscura*, *photographic apparatus*, the *magic lantern*, the *solar microscope*, the *photo-electric microscope*, etc. The two former classes yield virtual images, the last, with the exception of the *camera lucida*, yield real images.

General composition of optical instruments. Of the various instruments enumerated above those of the first two groups consist essentially of two lenses : one called the *object glass*, or *objective*, receives the light from the objects, and concentrates it in a focus where it gives a small image; the other, called the *eyepiece*, or *ocular*, acts as a magnifying glass, is near the eye, and serves to view the image formed by the object glass. In what are called *reflecting telescopes*, a concave mirror is used instead of an object glass. Generally speaking the object-glass and the eyepiece are not formed of a single glass, but of several, in order to obtain a greater magnifying power, and to correct chromatic and spherical aberration. These glasses are, moreover, mounted in long metal tubes, blackened on the inside so as to absorb the oblique rays, which would otherwise injure the sharpness of the image; these tubes can, moreover, be slided in or out, so that the glasses may be brought to the proper distance.

350. **Galileo's telescope.**—Like many grand discoveries, that of the telescope seems due to chance. For it is stated to have been made accidentally by the children of a Dutch spectacle maker at Middlebourg. Looking at a vane on the top of a church spire through a convex and concave glass, the latter being nearer the eye, they were surprised to see the object magnified, and apparently almost within reach. The father repeated the experiment, and arranged the two glasses in tubes, one which slided in the other, and thus constructed the telescope.

This telescope bears Galileo's name, for this illustrious astronomer was the first to direct it towards the heavens, and to make astronomical observations. It is stated that he was at Venice when he learnt that Zacharia Jans had offered to Prince Maurice of Nassau an instrument which brought objects nearer : he quickly

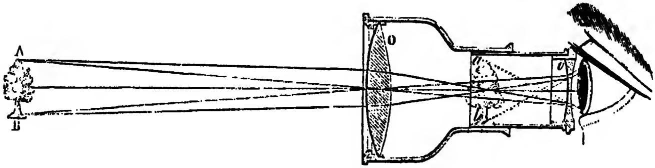

Fig. 268.

started for Padua, where, after meditating on the matter, he made some experiments, and in twenty-four hours rediscovered the telescope.

The telescopes constructed by Galileo were gradually improved from a magnifying power of four up to one of thirty times. By its means Galileo discovered the mountains of the moon, Jupiter's satellites, and the spots on the sun. From these numerous discoveries he acquired the name *Lynceus*, from one of the Argonauts, whose sight is said to have been so penetrating that he could see to the bottom of the sea.

Fig. 268 represents the arrangement of the lenses and the path of the rays in a Galileo's telescope. The object glass, O, is a double convex, while the eyepiece, *o*, is a double concave lens. If AB is the object observed, the rays, from any one of its points, A for instance, tend to form an image of this point beyond the object-glass; but meeting the double concave lens, *o*, these rays appear divergent, and seem to the eye which receives them as if they proceeded from

the point a; and it is there the image of A appears. In like manner the image of B is formed at b, so that a virtual image, λb, is formed, which is erect, and very near.

Galileo's telescope is very short and portable. It has the advantage of showing objects in their right position, and, further, as it

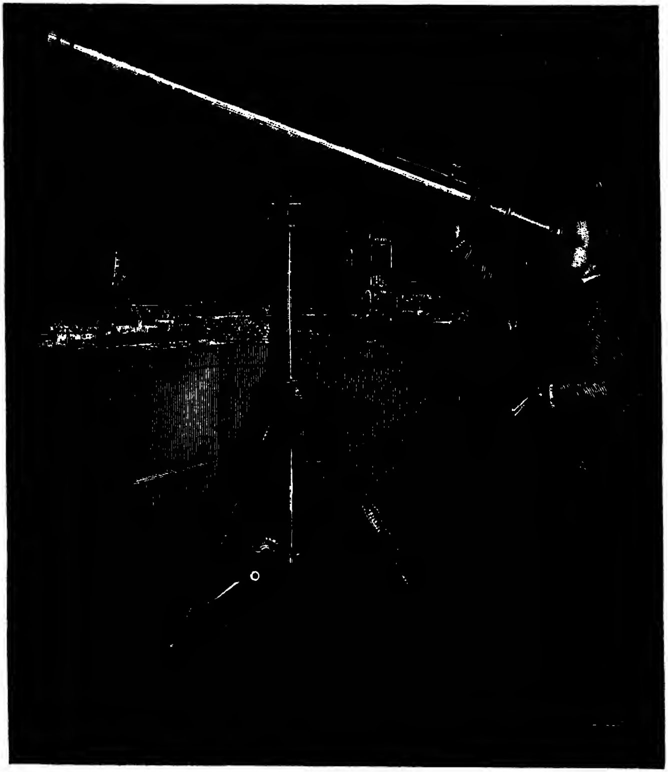

Fig. 269.

has only two lenses, it absorbs very little light: in consequence, however, of the divergence of the emergent rays it has only a small field of view, and in using it the eye must be placed very near the eyepiece. The eyepiece can be moved to or from the object

glass, so that the image is always formed at the distance of distinct vision.

Opera glasses are constructed on this principle. They are usually double, so as to produce an image in each eye, by which greater brightness is attained.

351. **Astronomical telescope.**—In order to obtain a greater field of view, in observing the stars a telescope with two condensing lenses is used. Its invention is due to Kepler, and it is known as the *astronomical telescope.* It gives reversed images of objects, but this is not objectionable in observing the stars.

Fig. 269 represents an astronomical telescope with a cast iron support, and mounted with a hinge motion on a column of the same metal; so that, not only can any degree of inclination be imparted to it, but it can be directed to any part of the horizon. By means of a handle and two toothed wheels the telescope can be raised or lowered at pleasure. On the side of the telescope is

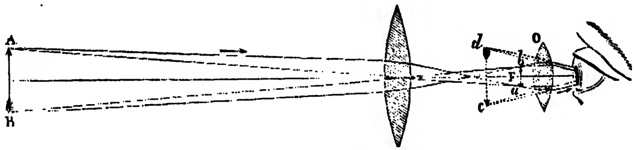

Fig. 270.

a smaller one called the *finder*; for as it magnifies less than the large one, it embraces a greater extent of sky, and therefore is more suited for finding any given star, which is then observed more minutely with the large glass.

Fig. 270 represents the arrangement of the glasses, and the path of the rays in an astronomical telescope. It consists of two double convex glasses; the object glass, which is of large diameter, and but slightly convergent, gives at *ab* a reversed and very small image of the star towards which the telescope is directed. This image is looked at through the eyepiece, O, which acts here as a magnifying glass, and which, for that purpose, is placed so that the image, *ab*, is formed between this glass and the principal focus, F. Thus the observer sees a reversed and greatly enlarged image of the star at *cd*.

As in all telescopes, the *eyetube*, that is, the tube in which is the eyepiece, slides in the other, so that it can be brought nearer or farther from the image, *ab*, which can thus be seen at the distance of

distinct vision. In powerful telescopes the eyepiece is not simple, as in the above case, but consists of a greater number of glasses, the object of which is not only to increase the magnifying power, but also to correct spherical and chromatic aberration.

The magnifying power of a telescope is greater the greater the diameter of the object glass, and the less its convexity; and the more convex, on the contrary, is the eyepiece. The greatest obstacle met with in the construction of these telescopes is the difficulty of manufacturing large object-glasses.

When the telescope is used to make an accurate observation of the stars, for example, their zenith distance, or their passage over the meridian, a *cross wire* is added. This consists of two very fine metallic wires or spider threads stretched across a circular aperture in a small metal plate. The wires ought to be placed in the position where the inverted image is produced by the object glass, and the point where the wires cross ought to be on the optical axis of the telescope, which thus becomes the *line of sight*, or *collimation*.

352. **Terrestrial telescope.**—The *terrestrial telescope* differs from the astronomical telescope in producing images in their right

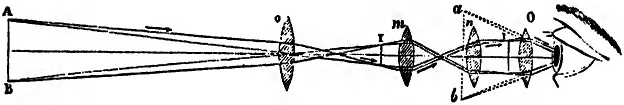

Fig. 271.

positions. This is effected by means of two condensing lenses, which are interposed between the object glass and the eyepiece, as seen in fig. 271. The object glass forming then, at I, a reversed image of the object, AB, the two glasses, *m* and *n*, impart such a direction to the rays traversing them, that, after having crossed between the two glasses, the rays reproduce an erect image at *i*. The eyepiece acts then just as in the astronomical telescope, giving a very near, erect, and magnified image, *ab*.

The terrestrial telescope is sometimes mounted on a stand, and sometimes held in the hand; its uses are too well known to need any description.

353. **Reflecting telescopes.**—The telescopes previously described are *refracting* or *dioptric* telescopes. It is, however, only in recent times that it has been possible to construct achromatic

lenses* of large size; before this, a concave metallic mirror was used instead of the object glass. Telescopes of this kind are called *reflecting* or *catoptric telescopes.* The principal forms are those devised by Gregory, Newton, Herschel, and Cassegrain.

Of these we shall describe the Newtonian telescope, which, after long disuse, has been restored to favour, in great measure owing to the improvements made in the construction of the concave mirror used in it.

Fig. 272 represents a section of a Newtonian telescope as modified by M. Foucault, and fig. 273 a perspective view. The principal piece of the telescope is a concave mirror, M, placed at the end of a long wooden tube. These mirrors were formerly of metal, and the difficulty of working such mirrors, so as to give them a perfect curvature, was so great, that the use of reflecting telescopes was virtually abandoned.

Foucault having discovered a method of silvering glass without

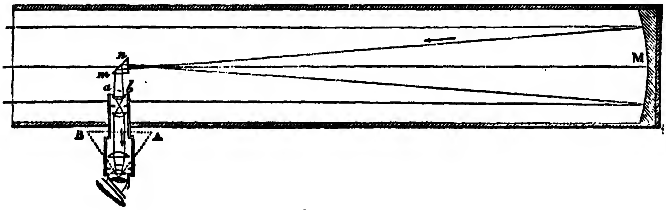

Fig. 272.

injuring its polish, and as glass is more easily worked than metal mirrors, reflectors for telescopes are now made of polished glass, silvered on the concave surface itself, the rays of light which come from the star observed are there reflected, and tend to form at the other end of the tube a real and very small image of the star; but these rays fall upon a small rectangular prism, *mn*, into which they pass without being refracted, and form with the large face, *mn*, such an angle of incidence that they are reflected out instead of being refracted (317). The image is then formed at *ab*, in front of a horizontal tube, in which are a series of magnifying glasses, which act as ocular, and give of the image, *ab*, a very amplified virtual image, AB.

Fig. 273 shows how the instrument is worked. The right hand of the observer holds a handle which transmits the motion to an endless chain, and this to two other chains, which pass round

pulleys, and enable the tube to be more or less inclined; with the left hand the same observer turns a small wheel, fixed to a screw, which enables him to move slowly the front part of the apparatus in a lateral direction, so that he can follow the star in its motion.

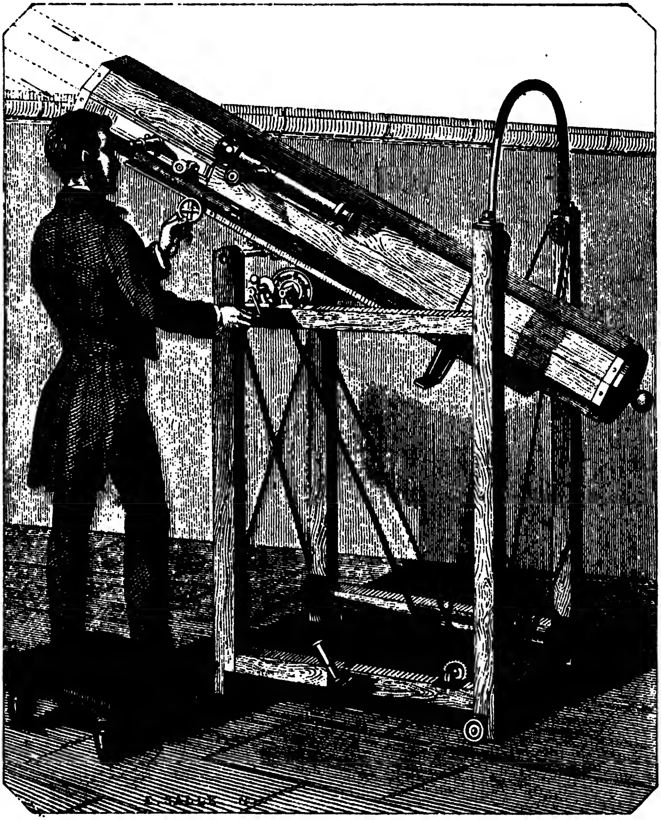

Fig. 273.

A little lower than the eyepiece and above the small wheel is a milled head, which works a small rack and pinion motion: this is fixed to a movable piece, which, at the same time, supports the prism, *nm*, and the eyepiece (fig. 272). By turning this milled head in

either direction, the prism and the eyepiece may be adjusted until the image, AB, is formed at the distance of distinct vision of the observer.

On the side of the tube is a smaller telescope, quite similar to the large one, but of far less magnifying power. This is the *finder*.

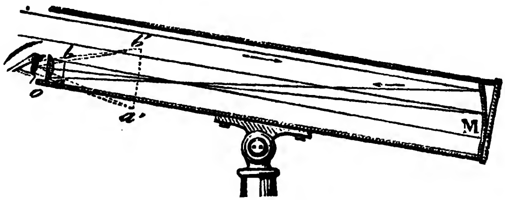

Fig. 274.

From its small magnifying power, not more than ten, it embraces a far greater extent of the sky, and is therefore more favourable for finding the desired star.

354. **Herschel's telescope.**—Sir W. Herschel's telescope, which, until lately, was the largest instrument of modern times, was constructed on a method differing from those described. The mirror was so inclined that the image of the star was formed on the side of the telescope near the eyepiece (fig. 274); hence it is termed the *front view* telescope. As the rays in this telescope only undergo a single reflection, the loss of light is less than in either of the preceding cases, and the image is therefore brighter. The magnifying power is the quotient of the principal focal distance of the mirror by the focal distance of the eyepiece.

Herschel's great telescope was constructed in 1789; it was 40 feet in length, the great mirror was 50 inches in diameter. The quantity of light obtained by this instrument was so great as to enable its inventor to use magnifying powers far higher than anything which had hitherto been attempted.

Herschel's telescope has been exceeded by one constructed by the late Earl of Rosse. This magnificent instrument has a focal length of 53 feet; the diameter of the mirror is 6 feet, and it weighs 8,400 pounds. It is at present used as a Newtonian telescope, but it can also be arranged as a front view telescope.

MAGNIFYING INSTRUMENT.

355. **Simple microscope.**—Microscopes are instruments which, giving very magnified images, enable us to observe objects which are too small to be seen with the naked eye. Two kinds are distinguished, the simple and the compound microscope.

The first of these is nothing more than a small highly convergent lens, which is used as a magnifying glass, as seen in fig. 275. The object observed is then placed between the lens and its principal focus, and the magnifying power is greater the more condensing is the lens. When it is rather large it is mounted in horn or in ivory, and is then known as a *lens*. It is frequently used to assist the

Fig. 275.

sight of the aged, or to facilitate certain kinds of work, which, as in watchmaking and engraving, require great accuracy. But no great magnification is thus attainable, and, in order to observe very small objects, the *compound microscope* is used, which is so called, for it is made up of several lenses.

356. **Compound microscope.**—Fig. 276 represents the mode of using a compound microscope, and fig. 277 the path of the luminous rays in the interior of the apparatus. The object observed, which is always very small, is placed at *a*, between two glass plates on a support called the stage. OA*o* is a brass tube in which are two condensing lenses, the *object-glass*, *o*, at the bottom, and the *eyepiece*, O, at the top. The object, *a*, being placed very little beyond the

principal focus of the eyepiece, we know that a real, erect, and greatly magnified image will be formed at *bc* (328). But as the eyepiece, O, is at such a distance that the image, *bc*, is between this glass and its principal focus, F, it follows that for an eye looking through it the

Fig. 276.

eyepiece acts as a lens (329), and gives at BC a virtual and amplified image of the first image, *bc*. It may thus be said, that the compound microscope is nothing more than a simple microscope

applied not to the object, but to its image already magnified by the first lens.

The magnification depends more especially on the object-glass. In order to increase its power it consists of two or three small lenses, superposed, as seen in H, on the right of the drawing (fig. 277). To the eyepiece a second glass is used, the object of which is less to obtain increased magnification than to render the images more defined by diminishing, as in telescopes, chromatic and spherical aberration. All the glasses are, moreover, achromatic. The magnifying power in compound microscopes has been carried to 1,800 times, and even more, but then what is gained in magnification is lost in definiteness. A good magnification does not exceed 600 in length and breadth, which amounts to a superficial enlargement of 360,000 times.

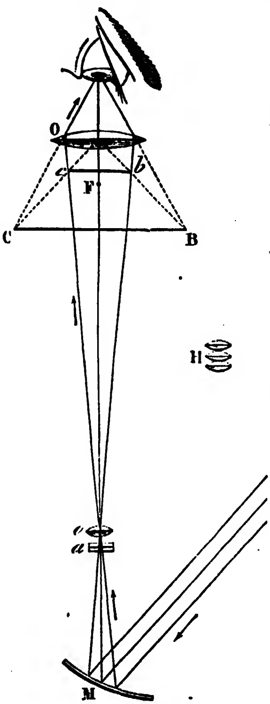

Fig. 277.

From the great magnification of the image the object must be powerfully illuminated. For this purpose, when it is sufficiently transparent, it is illuminated from below by a concave mirror, M, which concentrates upon it a large quantity of light, as shown in fig. 277. If the object is opaque it is illuminated above by a condensing lens, L (fig. 276), the focus of which is formed upon the object itself.

357. **Origin and use of the microscope.** — The invention of the microscope does not extend further back than the commencement of the seventeenth century, which is surprising, for it had long been known that a drop of water placed in a small hole in a thin opaque plate magnified objects seen through it. From the commencement of the first century, A.D., the philosopher Seneca announced that writing appeared larger under a glass globe containing water. Finally, in the thirteenth century, *spectacles* were used, that is, magnifying glasses, to assist the sight of the aged. The inventor

of the microscope is not known; it has, probably, only acquired its present form after numerous successive improvements.

The microscope has been the origin of discoveries in the vegetable and animal kingdom, as curious as they are varied. Botanists owe to it their most beautiful discoveries on the structure of the cellular tissue in plants, the circulation of the sap, the function of leaves in the respiration of vegetables. In entomology it has enabled us to discover a crowd of small animals which would otherwise have remained unknown from their extreme minuteness. Thus there have been observed, in vinegar and in sour paste, thousands of small grigs called *vibrions*; in stagnant waters myriads of animalcules, as remarkable for their fantastical forms as for their beautiful colours, their instincts, their warlike or sociable manners. Mould presents the appearance of small mushrooms with the most brilliant colours. In short, any object seen through the microscope becomes an object of astonishment and admiration: thus, for instance, a hair, a piece of silk thread, the eye or wing of a fly, a bee's sting, a spider's claw, a cat's or mouse's hair, the down of fruit, the scales of a butterfly's wing or of fish, starch grains, spider-web, etc., etc., everywhere we recognise the infinite perfection of nature's works.

The microscope may also be advantageously used to recognise the fraudulent mixtures in cloths of various kinds, by giving a means of ascertaining whether they contain wool or silk, linen or cotton.

CHAPTER VIII.

OPTICAL RECREATIONS.

358. **Magic lantern.**—In the instruments that still remain to be described, the object is to project on a screen reduced or enlarged images of an object, so as to exhibit them to a number of spectators, or to utilise them for drawing.

The oldest and most simple of these apparatus is the *Magic lantern*, which, as everyone knows, is one of the first physical instruments placed in children's hands. It was invented by Father Kircher, a German Jesuit, about 200 years ago, and is used to project a magnified image of small objects painted on glass on a white screen in a dark room (fig. 278). It consists of a tin plate box

in which there is a lamp placed in the focus of a concave mirror, M (fig. 279). The reflected rays fall upon a condensing lens, L, which concentrates them on the figure painted on a glass plate, *ab*. There is a system of two lenses, *m*, acting as a single one of great magnifying power, at a distance from *ab* of rather more than its focal distance. At this distance the system of two lenses acts as in the experiment (fig. 278); that is, a real and very much magnified image of the figure on the glass is produced on the screen. The

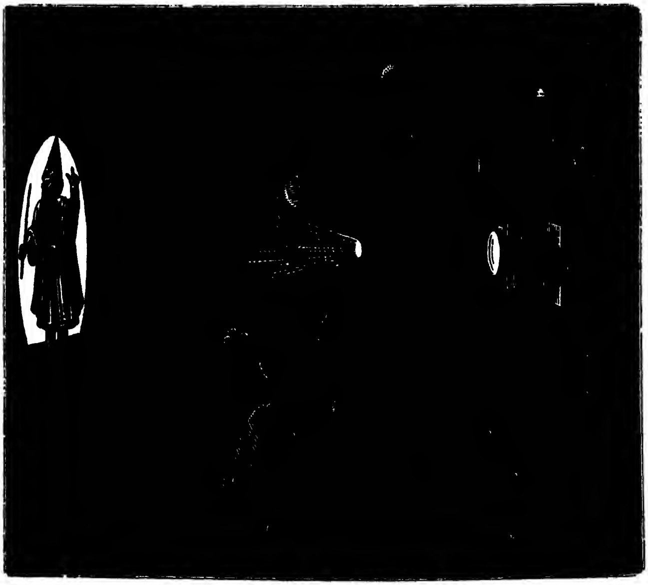

Fig. 278.

image is made erect by placing in the lantern the glass painted in such a manner that the design is reversed. The image, AB, is formed at so much the greater distance, and is so much the more amplified, the nearer the glass, *ab*, is to the principal focus of the system of lenses, *m*, and the greater the magnification of this system.

359. **Phantasmagoria.**—This is only a modification of the magic lantern, and dates from the end of the eighteenth century: its name is derived from two Greek words, which signify *assemblage of phan-*

ioms, for it was originally used to produce fright, by making spectres appear in darkness.

The internal arrangement of the phantasmagoria is just the same as in the magic lantern, the only difference being, that in the magic lantern the image projected on the screen is always of the same size, while, in the case of the phantasmagoria, this size may be varied at pleasure. To understand how this is effected, let us refer to fig. 279, which represents the arrangement of glasses in the magic lantern. The lenses, *m*, which are used to project the images on the screen, being always at the same distance from the painted glass, *ab*, the image, AB, is always at the same distance, and is always therefore of the same size. Now if one of the lenses, *m*, be brought nearer the glass, *ab*, it follows from the properties of lenses (328) that the image will be found at a greater distance, and will be larger. Hence the effect sought requires two movements; one which brings the system of lenses, *m*, nearer the painted glass, to amplify the image; the other, which makes the whole apparatus re-

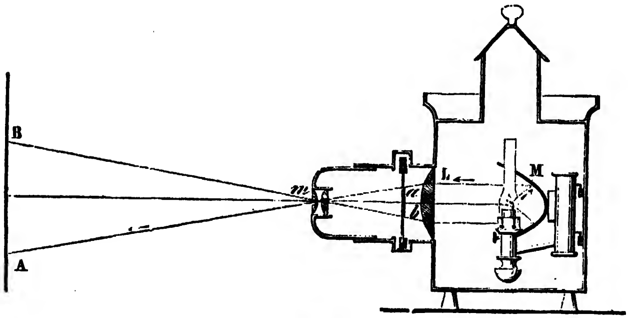

Fig. 279.

cede, so that the image, while being moved away, is always formed upon the same screen as at first.

To obtain this double effect the whole apparatus is mounted upon four small wooden wheels covered with cloth, so that they roll noiselessly on the floor. Figure 280 represents a phantasmagoria thus arranged, with the difference that in the figure it is double, that is, consists of two apparatus united. We shall presently see the reason for this double use, and for the moment we shall only consider one of the parts. The front of the box is provided with a conical brass tube: in this tube is the lens of projection, which is

not fixed, but may be advanced or receded by means of a milled head and screw, which the experimenter turns with the hand.

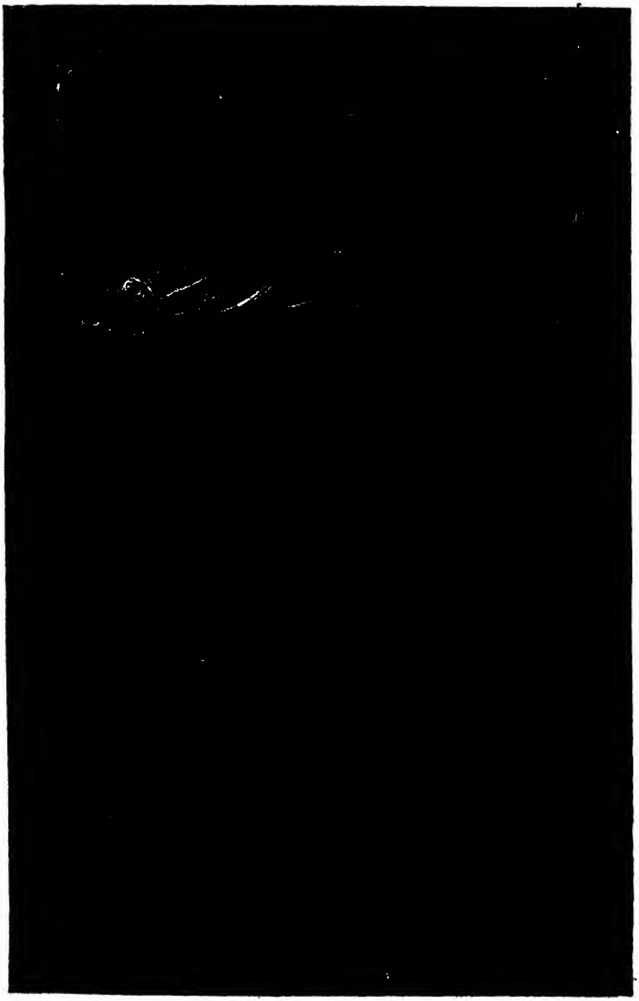

Fig. 280.

A large white sheet is stretched in front of the apparatus, and the spectators are on the other side of the sheet. The whole being in profound darkness, the experimenter is careful first of all to keep the projecting lens away from the glass, on which are painted the objects he desires to show. Thus there is at first formed on the sheet a very small image of the object. Then, with one hand, the experimenter brings the lens near the painted glass, while with the other he draws towards himself the apparatus, and away from the cloth; the image projected on the latter gradually increases, and ultimately becomes very large. But the spectators, who are prevented from seeing whether the position of the image changes or not, and who see the image very distinctly through the cloth, fall into the illusion that its increase in size is due to its coming nearer them. Some authors have supposed that use was made of the phantasmagoria in remote antiquity, and, by means of apparatus of this kind, those initiated into the mysteries of Isis and Ceres were terrified, and the infernal deities evoked were made to appear. Yet nothing indicates that lenses were then known, but concave mirrors would be sufficient for producing effects analogous to those of the phantasmagoria.

360. **Polyorama, or dissolving views.**—The polyorama is an application of the phantasmagoria. This is then double, as represented in fig. 280, and the two systems of lenses converge towards the same point of the cloth which receives the image. Two pictures on glass are used representing the same view under different conditions; for example, Mount Vesuvius seen at daytime, calm, and with a slight cloud of smoke rising from it; the other volcano seen at night vomiting forth flames and torrents of fiery lava. Having arranged these glasses, each in one of the phantasmagoria, and the lenses being so arranged as to project the magnified images on exactly the same part of the cloth, the diaphragm of the one containing the picture representing the effect of day is opened; the other remaining closed. Then when the image has for some time been exposed to the view of the spectators, a mechanism, *a*, is worked, which gently closes the one which has been exposed, and opens the other. It follows, that in gradually passing through all the shades of light, the image which produces the effect of day disappears, while it is gradually succeeded by the effect of night represented on the other. In like manner, too, the effect of the moon rising may be made to succeed to sunset; to a calm and transparent sea, a tempest; to a smiling landscape, a snow effect, and so

forth. Henee the name *polyorama*, from two Greek words, which signify several views.

361. **Photo-electrical microscope.**—This apparatus is based on the same principles as the magic lantern and the phantasmagoria. But, as in these apparatus, the subjects painted on glass have at once size, no great enlargement is required, and therefore the illumination need not be very intense. Whereas objects, the image of

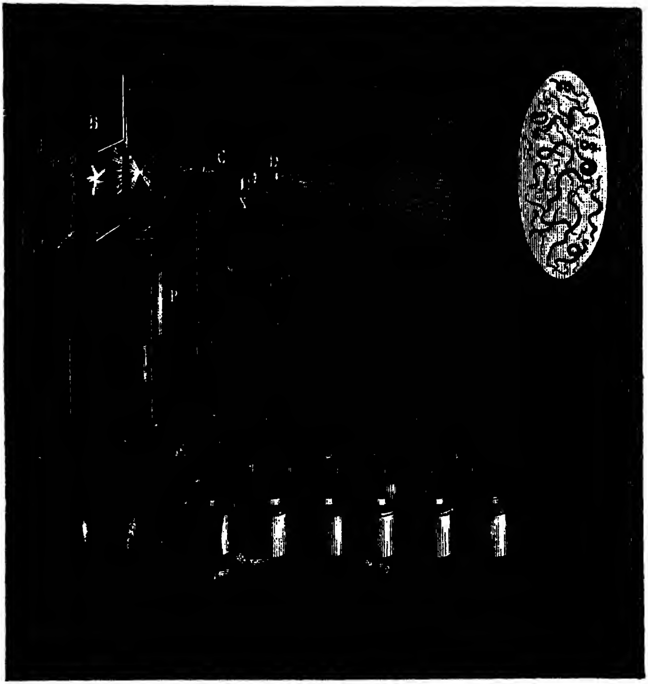

Fig. 281.

which is reproduced by the photo-electric microscope, being very small, should be considerably magnified, and the light must therefore be very powerful, or else the image will be confused and indistinct. Hence the apparatus is illuminated by the powerful light which the electric battery yields.

Figure 281 represents the use of the photo-electric microscope. At the base of the vessel is a series of vessels which serve for the disengagement of electricity, and which we shall presently describe as the electric battery. From these vessels the electricity passes by two stout copper wires to two rods of charcoal, contained in the box B. Thus charged with electricity, these carbons become heated to incandescence, and to emit such a bright light that the eye cannot support it. A reflector, I, sends the luminous rays in the direction of the tube, C, where they meet two condensing lenses, which concentrate them on the very small object which is to be magnified, and which is arranged between two glass plates, X. The rays pass from thence into a tube D, where there is a system of condensing lenses intended to produce the same effect of projection as the lenses, *m*, in the magic lantern (358); that is, it is a system of lenses which produces on a white screen at a distance an extremely magnified image of the small object placed between the glass plates. The tube, D, is movable, and may be approached to or receded from the object, so as to vary the magnification.

In the adjacent figure, the image projected on the screen is that of the infusoria which are found in paste when it has fermented. A small quantity is mixed with water, and a few drops put in a small glass box with parallel faces, which is placed at X. A multitude of these animalculæ are seen on the screen, ten or twelve inches in length, which move about in a confused mass, and soon die in consequence of the heat which is concentrated along with the light in the focus of the lenses.

362. **Experiments with the photo-electric microscope** are among the most interesting in the whole range of physics. By its means, objects of extreme minuteness may be exhibited, greatly magnified, to a large number of spectators. A hair, for example, looks like a broomstick; a flea like a sheep; the itch-tick, an animalcule found in itch pustules, and by which this disease is propagated, appears like a man's head; the same is the case with the animalcules found in decayed cheese, although these cannot be seen by the naked eye. One of the most remarkable experiments is that showing the circulation of the blood. This is made by placing between two glass plates the tail of a living tadpole, that is to say, the young of a frog, before its upper and lower limbs are developed. There is then observed on the screen a kind of illuminated map, all the rivers in which appear to flow very rapidly: this is the blood which circulates in the veins. A very beautiful experiment is the

crystallisation of salts, and especially of sal ammoniac. This salt is dissolved in water, and a drop of the solution is spread on a glass plate, which is placed in the apparatus. As the heat makes the water evaporate, a vegetation quickly forms, which is surprising from the promptitude with which the crystalline molecules group themselves together to produce magnificent ramifications like fern leaves.

The apparatus we have described is sometimes modified, so as to be illuminated by sunlight, and is then called the *solar microscope.* It is also illuminated by the intense light produced by allowing the oxyhydrogen flame to impinge upon a piece of lime. It is then called the *oxyhydrogen microscope.*

363. **Camera obscura.**—A Neapolitan physician, Jean Baptiste

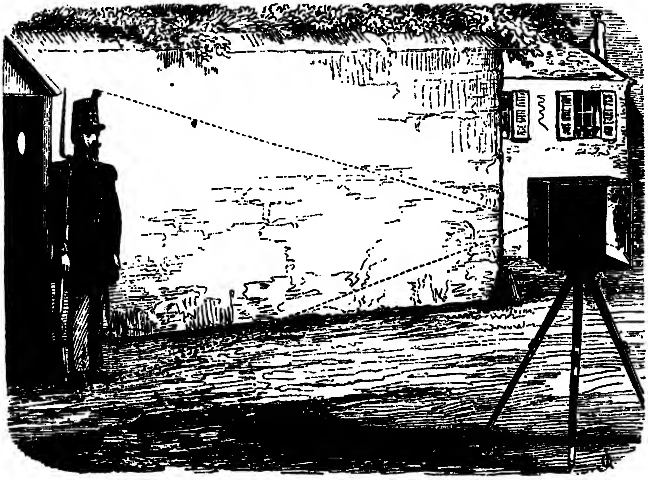

Fig. 282.

Porta, first observed in 1680, that if a very small hole be perforated in the shutter of a *dark room,* one that is quite deprived of light, all objects which can reach the hole depict themselves on the opposite screen, and of so much the smaller dimensions the nearer this screen is to the aperture.

Porta also found, that by fixing a double convex lens in the aperture, and placing a white screen in the focus, the image was much

brighter, and more definite. In both cases the images are inverted. Fig. 282 shows how images formed in the camera obscura are reversed upon the screen. It is due to the rays crossing on entering the aperture. It follows in fact, that rays from the higher parts of the object proceeding in a straight line meet the lower part of the screen, while the reverse is the case with rays from the lower part. The colouration of the image is readily understood by observing, that the reflected rays are of the same colour as the reflecting body; that is, that a red body reflects red rays, a yellow body yellow rays,

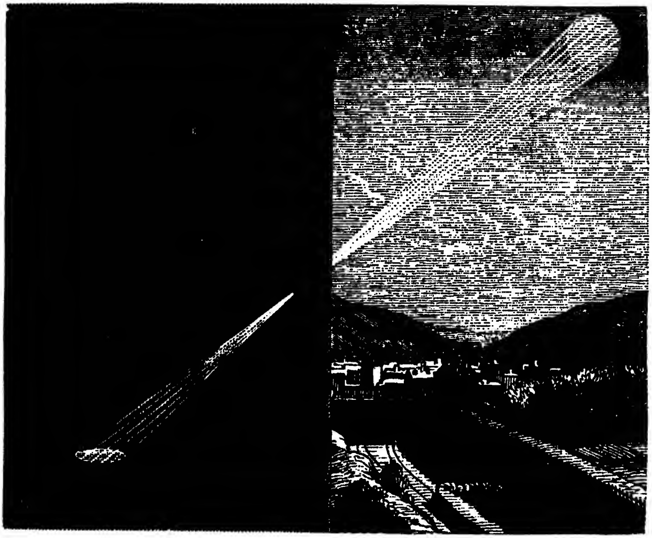

Fig. 283.

and so on; each portion of the image is formed by the coincidence of rays of the same colour as the corresponding part of the object it represents.

The images formed in the camera obscura have the peculiarity of being independent of the shape of the aperture through which the rays enter ***provided this is very small***, that is, that whether this aperture is round, square, or triangular, the image formed on the screen is always a faithful reproduction of external objects, and not

of the hole made in the shutter. To account for this phenomenon let us consider the case of a pencil of solar light passing into a dark room of any shape whatever (fig. 283). From the magnitude of the sun this hole is really nothing more than a point; whence it follows, that the whole of the rays which traverse it represents an immense luminous cone, of which the hole is the summit and the sun the base. By their being prolonged into the chamber these rays give rise to a second cone resembling the first, but far smaller; and if this second cone falls upon a screen which is perpendicular to the straight line joining its summit to the centre of the sun, it produces

Fig. 284.

on this screen a circular image like the sun. If the screen is obliquely inclined towards this line, as represented in fig. 283, the image is elongated, but it never has the shape of the aperture unless the screen is very close.

In the same manner we must explain the luminous circles formed on the ground under an avenue of trees illuminated by the sun, whatever be the shape of the spaces on the foliage through which the light passes, a circular image of the sun is projected upon the ground (fig. 284).

364. **Rectification of images of the camera obscura.**—When

in a camera obscura a monument or a landscape is to be reproduced, the image must be rectified. For this purpose the apparatus is arranged as in fig. 285. A little above the hole through which the light enters a plane mirror is placed inclined, so as to send the rays towards a condensing lens fixed at the end of a tube. Below this lens, and at its focus, is placed a white screen, on which external objects depict themselves. The images thus obtained, rectified by

Fig. 285.

the reflection of the rays from the plane mirror and their passage through the lens, are not merely admirable from their fidelity and colour, but they do what no other kind of reproduction can do, they reproduce motion. If the camera obscura is set up in front of a promenade, or a public place, the images of the passers-by are seen

to move across the screen with such fidelity that they can be recognised.

The camera obscura gives in this manner an amusing spectacle; it may, moreover, be used in drawing, for even a person who cannot draw can trace with a pencil the outlines of the image, and trace it on a screen. For this latter purpose the following arrangement is usually adopted.

365. **Portable camera obscura.**—To take views by means of the camera obscura, it should be light and portable, and should not occupy too large a space. Fig. 286 represents a simple and con-

Fig. 286.

venient form of the apparatus. It consists of a wooden tripod, supporting a board of the same material, and surrounded by a curtain which forms a small tent, in which the artist places himself. In the centre of the tent is a small table resting on a tripod, on which is produced the image. At the top of the apparatus, in a brass tube open at the side, is a glass prism, which reproduces both the effect of the inclined mirror and of the lens in the camera obscura described above. For this purpose the first face of the prism is convex, as represented in fig. 287. Hence on passing

into this prism the rays from a distant object converge; then undergoing a total reflection on the side *m* (317), they are sent towards the third face, which is concave, whence they emerge with the same degree of convergence that they had before traversing the

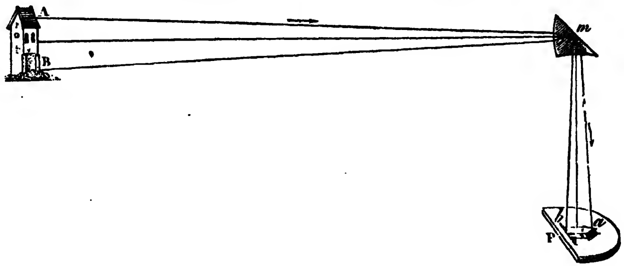

Fig. 287.

lens, and there is thus reproduced at *ab* on the table P the image of the object AB, from which they come. The designer takes then the outlines of this image on a sheet of paper.

PHOTOGRAPHY.

366. **Photography.**—*Photography* is the art of fixing the images of the camera obscura on substances *sensitive* to light. The various photographic processes may be classed under three heads: photography on metal, photography on paper, and photography on glass.

Wedgwood was the first to suggest the use of chloride of silver in fixing the image; and Davy, by means of the solar microscope, obtained images of small objects on paper impregnated with chloride of silver; but no method was known of preserving the images thus obtained, by preventing the further action of light. Niepce, in 1814, obtained permanent images of the camera by coating glass plates with a layer of a varnish composed of bitumen dissolved in oil of lavender. This process was tedious and inefficient, and it was not until 1839 that the problem was solved. In that year, Daguerre described a method of fixing the images of the camera, which, with the subsequent improvements of Talbot and Archer, has rendered the art of photography one of the most marvellous discoveries ever made, either as to the beauty and perfection of the results, or as to the celerity with which they are produced. Fig. 288 gives a vertical section of the kind of camera obscura used by

photographers. It consists of a rectangular wooden box in two pieces, one of which, C, is fixed, and the other, B, can be drawn in or out like a drawer. In the front of the box is a brass tube, A, in which is a condensing lens, L, which is fixed. In A is a second tube which can be moved backwards or forwards by a rack and pinion moved by the milled head, D. In this second tube is a second lens, L′, which, by the motion of the tube, is brought nearer or further from the lens, L. The combination of the two lenses forms what is called an object glass with combined lenses. The advantage of this arrangement is that it works more rapidly than an object glass with a single lens, has a shorter focal distance, and can be more readily focussed.

On the face of the box opposite the object glass is a screen of ground glass, E, which can be removed at will, and on which a reversed image of the object is formed. Thus, if a portrait is to be taken the person is placed at a distance of three or four yards from

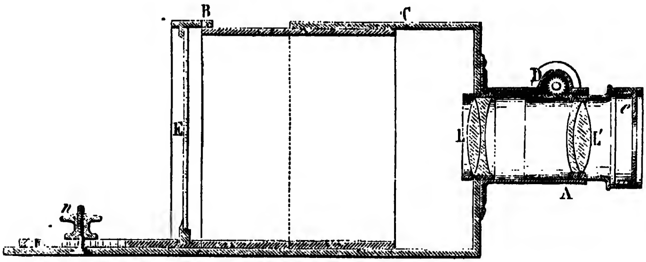

Fig. 288.

the camera, which is then adjusted until the image is formed in the proper position on the glass. It is then placed in exact focus by slowly approaching or removing the lens, L′. The glass is contained in a frame which can be easily removed and replaced by the slide containing the material on which the photograph is to be taken.

The photographs on metal, or *daguerreotype*, so called from Daguerre the inventor, are now seldom used. The photographic methods in glass and paper are infinitely varied, not as regards the optical part, but as concerns the substances employed, and therefore as regards the chemical reactions involved. We will content ourselves with describing the ordinary method of taking a portrait on paper.

For this purpose what is called a *negative* must first be taken—an inverse image of the object, that is to say, in which the light parts are dark, and *vice versâ.* With this view a glass plate is coated with a thin layer of *collodion* (gun cotton dissolved in ether), containing a certain quantity of iodide of potassium. This plate is then placed with the coated side in a solution of nitrate of silver. By the chemical reaction between the iodide of potassium and the nitrate of silver a coating of iodide of silver is formed on the plate which is sensitive to light, and hence the operation must be performed in a dark room. The plate is then placed in the slide, and inserted in the camera instead of the focussing-glass. The slide is so constructed that the plate can be instantaneously exposed to or cut off from the action of light. After exposure for a suitable time the slide is removed to a dark room. No change is visible in the plate, but on pouring over it a solution called the *developer*, an image gradually appears. The principal substances used for developing are protosulphate of iron and pyrogallic acid. The action of light on iodide of silver appears to produce some molecular change, in virtue of which the developers have the property of reducing to the metallic state those parts of the iodide of silver which have been most acted upon by the light. When the picture is sufficiently brought out, water is poured over the plate, in order to prevent the further action of the developer. The parts on which light has not acted are still covered with iodide of silver, which would be affected if the plate were now exposed to the light. It is, accordingly, washed with solution of hyposulphite of sodium, which dissolves the iodide of silver and leaves the image unaltered. The picture is then coated with a thin layer of spirit-varnish, to protect it from mechanical injury.

When once the negative is obtained, it may be used for printing an indefinite number of positive pictures. For this purpose, paper is impregnated with chloride of silver, by immersing it first in solution of nitrate of silver and then in one of chloride of sodium; chloride of silver is thus formed on the paper by double decomposition. The negative is placed on a sheet of this paper in a copying frame, and exposed to the action of light for a certain time. The chloride of silver becomes acted upon—the light parts of the negative being most affected, and the dark parts least so. A copy is thus obtained, on which the lights of the negative are replaced by shades, and conversely. In order to fix the picture, it is washed in a solution of hyposulphite of sodium, which dissolves the unaltered

chloride of silver. The picture is afterwards immersed in a bath of chloride of gold, which gives it tone.

367. **Positives on glass.**—Very beautiful positives are obtained by preparing the plates as in the preceding cases; the exposure in the camera, however, is not nearly so long as for the negatives.

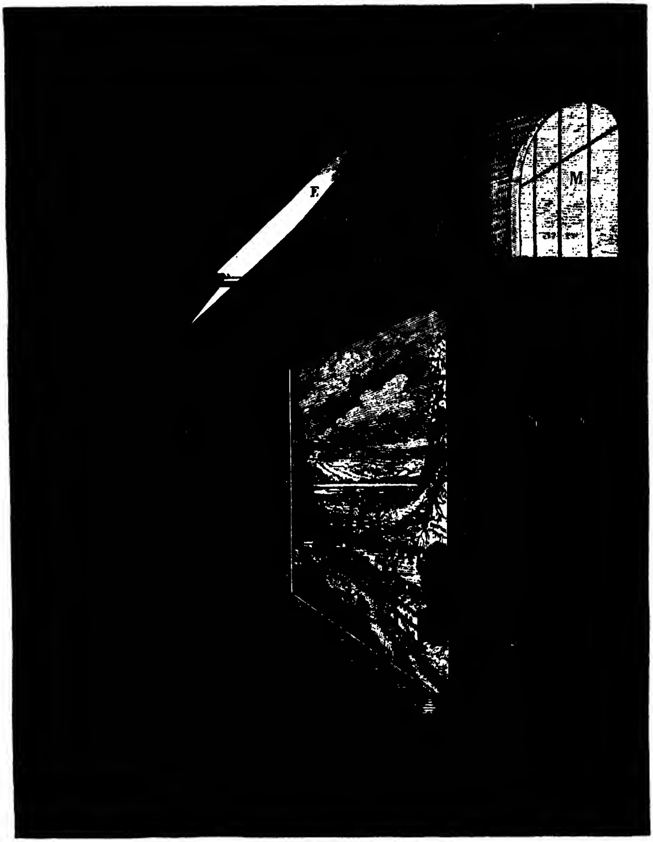

Fig. 289.

The picture is then developed by pouring over it a solution of protosulphate of iron, which produces a negative image; and by

afterwards pouring a solution of cyanide of potassium over the plate, this negative is rapidly converted into a positive. It is then washed and dried, and a coating of varnish poured over the picture.

368. **Diorama.**—The name diorama is derived from two Greek words which signify *viewed through*, and is applied to pictures painted on muslin or on calico, so as to represent two opposite effects like the polyorama, according as the pictures are seen by reflection or by transmission.

The picture is arranged vertically in a dark room as represented in fig. 289. The first effect, that painted on the front of the cloth, is illuminated by reflection: the second, that painted behind, is illuminated by transmission. With this view light enters through a window, M, in an upper story, and is sent to a screen, which reflects it towards the picture, and lights it from the front : behind the picture is another window, N, which, when open, lights it in front. The shutters, NN, being closed, the spectators first see the subject on the front of the cloth. By a simple arrangement, a shutter, A, which slides without noise in two grooves, is made to advance, and when the picture is scarcely illuminated, by degrees the shutters, NN, are opened ; and then the picture painted on the other side of the cloth appears through it, and is substituted for the former one.

The diorama was invented by Daguerre, who had great skill in this kind of painting. The above figure represents the valley of Goldau before the terrible landslip, which took place on September 2, 1806. At the moment light was intercepted by the screen, lightning flashed, thunders groaned, and there were all the effects of a violent storm. On the return of day, the rocks had given way, the lake had been partly filled up, and the chalet destroyed ; in short, the image of ruin and desolation was reproduced with astounding fidelity.

369. **Ghost scenes.**—We will give here a description of a curious optical effect, which was first introduced some years ago in the London theatres, under the name of *ghost scenes.*

In order the more readily to understand the appearance of these spectres, let us recal an effect which everyone has observed. When at night on a railway we look at the windows of carriage doors, we see a pale and indistinct image of the travellers inside. This is an effect of reflection from the panes, which reflect the light that illuminates persons and objects placed in the compartment ; and the faint light of the images arises from the fact, that the panes allowing great part of the light to be transmitted, send very little towards the

observer. A similar effect is produced when in the evening, in a well-lighted street, a window front, which is little or not at all

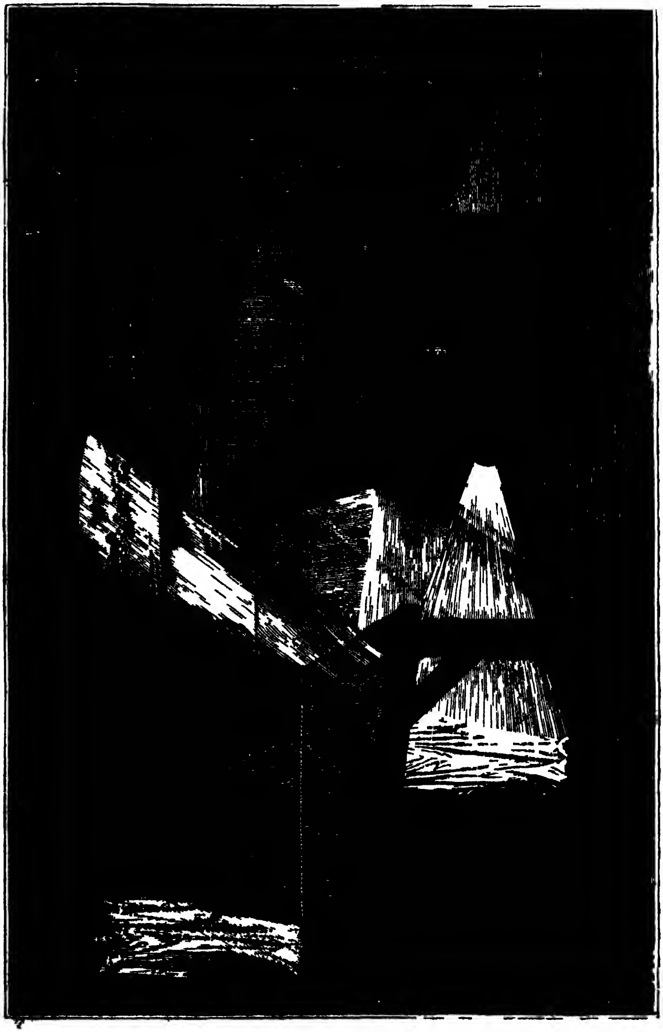

Fig. 90

ugnted, is looked at. The observer sees his own image and that of the passengers on the other side of the panes. These effects are not seen in full daylight, for the images which tend to be reproduced are effaced by the brightness of the light.

These effects have been utilised in public to simulate the appearance of ghosts. Fig. 290 represents the arrangement of the apparatus intended for this use. On the floor of the stage, and not visible by the spectators, is an actor covered by a sheet, and intended to represent the ghost. Between the actor and the public is a dark lantern, in which is the lime light, which gives an extremely bright light. An assistant directs the light upon the actor, and the white cloth, thus powerfully illuminated, sends its rays towards an inclined sheet of glass, placed near the assistant. This glass, which is silvered, sends almost all the reflected light towards a second sheet, which is not silvered on the same scene. This latter plate acts like those in carriages and in shopwindows, which we have mentioned above, and being traversed by the greater part of the incident rays, send but little light towards the spectator. Yet, as during this time, care is taken that the illumination in the room is very faint, the light is sufficient to give a cloudy image of the actor placed under the stage.

If another actor enters the scene the public see very distinctly through the glass, which is carefully concealed by hangings and decorations; and if this actor is behind the plate at the same distance as the image, he can join his action with that of the ghost, and produce a complete illusion.

The same effects are produced with a single plate, but as its obliquity tends to give inclined images. to rectify them, the actor under the theatre must hold himself so much inclined as to render his play very difficult. With the two sheets represented in the above figure, the actor retains his natural position.

VISION AND STEREOSCOPE.

370. **Structure of the eye and mechanism of vision.**—Although the description of the eye belongs to physiology rather than to physics, we may give an account of this organ, which is not merely a true optical instrument, but an instrument of inimitable perfection; for it has neither spherical nor chromatic aberration; and has moreover the remarkable property of adapting itself at once to see distinctly at all distances, which the best optical instruments do not do.

The eye is almost spherical in shape, and is surrounded by several membranes, which fig. 291 represents open from back to front. The front part of the eye is a perfectly transparent membrane, *c*, called the transparent cornea, and which is commonly called the *white of the eye.* At a small distance behind the cornea is a membranous diaphragm, *hi*, called the *iris*; it constitutes the variously coloured disc which appears in the middle of the white of the eye, and to which is due the colour. In the centre of the iris is an aperture called the *pupil*; in man this is circular, and in the cat narrow and elongated, and through it rays pass into the eye. Behind the iris, but very near it, is the *crystalline*, which is a transparent mass, having the shape and fulfilling the functions of a double convex lens. The whole of the back part, from the crystal-

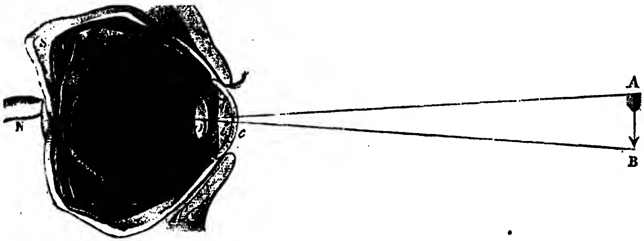

Fig. 291.

line to the bottom of the eye, is filled with a gelatinous transparent mass, like white of egg, which is called the *vitreous humour.* In front of the eye, between the crystalline and the cornea, is a perfectly transparent liquid called the *aqueous humour.* The whole of the back inside part of the eye is lined with a soft, whitish, transparent membrane, R, called the *retina*; it is nothing more than the extension of a nerve, N, which proceeds to the brain, and transmits the sensation of vision, whence it receives the name *optic nerve.* Behind the retina is a second membrane, C, called the *choroid*, which is impregnated by a black matter, that absorbs all rays which should not coincide in vision. Lastly, a membrane, S, the *sclerotica*, surrounds the whole eyeball behind, and joins the transparent cornea in front.

These details being known, we may easily account for the mechanism of vision; for the eye is nothing more than a small camera obscura (363), of which the pupil is the aperture, the crystalline is the condensing lens, and the retina is the screen on which the

image is formed. Thence the optic nerve, carrying to the brain the impression produced by the vibrations of the ether on the nervous system of the retina, enables us to perceive external objects. In accordance with this explanation, we should see objects reversed, and not in their natural position. The inversion of images in the eye has greatly occupied both physicists and physiologists, and many theories have been proposed to explain how it is that we do not see inverted images of objects. Some have supposed that it is by custom, and by a regular education of the eye, that we see objects in their true position, that is to say, in their position relative to us. The visual impression becomes corrected by the impression of other senses, such as that of touch. Müller, Volkmann, and others contended that, as we see everything inverted, and not simply one object among others, nothing can appear inverted, because terms of comparison are wanting. It must, however, be admitted that none of these theories is quite satisfactory.

371. **Distance of distinct vision. Short and long sight.**—We know that in double convex lenses the distance of images from the lens increases or diminishes as the object is approached or receded (325). Hence, according to the distance of the objects looked at, it would seem that the image formed by the crystalline should be sometimes formed exactly on the retina, and sometimes a little in front of or behind this membrane. Only objects placed at a certain distance should then be seen distinctly; all those nearer or further should appear confused. This does not occur with a well-shaped eye, for it sees objects distinctly at very different distances; whence it is concluded, that the eye has the power of rapidly accommodating itself, so that the image is always formed exactly upon the retina.

Yet, though the eye can well distinguish objects at very different distances, there is in the case of each person a distance at which objects are more distinctly seen than at any other. This distance is called *the distance of distinct vision*; it varies with different persons, and often in different eyes in the same individual; for small objects like print it is usually about ten to twelve inches.

Those who can only see well at shorter distances have a defect in the shape of the eye; they are said to be *myoptic* or *short-sighted*, from two Greek words which signify close the eyes; for myoptic persons, in order to see more distinctly, do in fact involuntarily half close the eyes. If the distance of distinct vision is greater than ten or twelve inches, that is also due to a malformation of the eye, and

those affected by it are called long-sighted or *presbyoptic*, from a Greek word which signifies *aged*, for this defect is usually met with in aged persons.

Myopy, or short-sight, results from too great a convexity of the cornea, or of the crystalline. The eye too convergent, the rays of light are refracted in such a manner, that instead of forming their focus exactly on the retina, they form it a little in front, and therefore the image which this membrane perceives is confused. But if objects are approached to the eye, the image recedes, and is formed exactly on the retina, when the objects are sufficiently near, which explains why short-sighted persons only see objects when they are very close. They can also see more distinctly by contracting the pupils, or by looking through a small hole perforated in a card; for then, as the diameter of the luminous pencil which penetrates into the eye, the rays mainly penetrate the crystalline at the centre, and being therefore less affected by its excess of convexity, they form the focus at a greater distance. Myopy is mainly met with in young people; as they grow older, the convexity of the eye diminishes, so that their sight generally becomes better, when that of other people becomes worse.

Presbytism, or long-sight, is due to the flattening of the crystalline, as the eye is then no longer sufficiently converged, the rays instead of forming their focus on the retina tend to form beyond it, whence it arises that the eye only observes a confused object. But as the objects recede, the image comes nearer the crystalline, and is ultimately formed exactly on the crystalline, when objects are sufficiently distant; which explains why long-sighted persons only see objects when they are distant.

Short-sight is remedied by the use of diverging lenses before the eyes; by the action of these glasses, as the pencil is spread out before entering the eye, the focus of the crystalline is receded as far as the retina, provided the degree of divergence of the glasses is suitably adapted to the excess of convexity of the crystalline. For far-sight, on the contrary, condensing lenses should be used, so as to correct the want of convexity of the crystalline. As the rays then become more convergent before entering the eye, the image, which would otherwise be formed beyond the retina, approaches it, and is ultimately formed exactly upon it.

For a long time double concave lenses were exclusively used for short-sight, and double convex for far-sight. We strongly recom-

mend, however, the concavo-convex lenses represented in O, in fig. 241 for long-sight, and those in R (fig. 242) for short-sight. These are called *periscopic glasses*, from two words meaning *to see round*; for, as their shape better enables them to embrace the eyeball, they facilitate vision in all directions; and, as they do not deform objects, they do not fatigue the eye like other glasses.

372. **Binocular vision.**—Although we have two eyes, and when we fix them on the same object, each forms its own image upon the retina, yet we only see one object, just as with two ears we only hear one sound. Various hypotheses have been made to account for single vision with two eyes. Some have considered it as an effect of habit, others assigning to it a physiological cause, have assumed that two points similarly placed on the two retinas correspond to the same nervous filament which, coming from the brain, bifurcates towards each eye. Hence the two impressions simultaneously produced on the two retinas result in a single sensation.

Not only does simultaneous vision with two eyes enable us to see bodies with greater lustre, but it gives us the impression of relief, as the stereoscope well shows.

373. **Stereoscope.**—The *stereoscope*, so called from two Greek

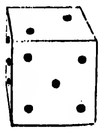

Fig. 292.

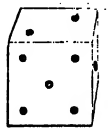

Fig. 293.

words which mean *perception of solidity*, is an ingenious object, which was invented by Sir C. Wheatstone, and modified to its present form by Sir D. Brewster.

To understand the effect of the stereoscope, let us observe that, when we look at an object with two eyes, each eye does not see it under exactly the same aspect, but under a slightly different perspective. Thus let a small object, such as a dice, be successively viewed with one eye, at a slight distance, without moving the head. If the cube be just in front of the observer, looking at it with his left eye, he will see this face, and a small portion of the left side, the other being concealed (fig. 292); if, on the contrary, he views it with the right eye, he sees the front and a portion of the right side,

the other being hidden (fig. 293). Thus the two images formed on the retina are not quite identical, for each corresponds to a different point of view. It is this difference in the images which gives us the sensation of relief in bodies, and enables us to appreciate their shape and their distance.

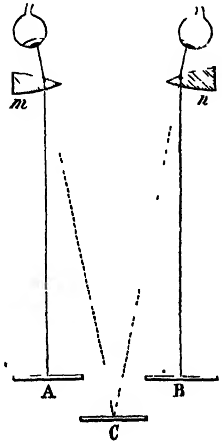

Fig 294

This may be confirmed by making two drawings of the same object, taken respectively with the perspective belonging to the right and to the left eye; then, as each eye looks separately at the drawing through prisms or lenses, which make the two drawings coincide, by giving the rays of light the same direction as if they converged from a single object, the impressions produced upon each retina will be the same as if the object itself were viewed. The illusion is in fact so complete, that, however prejudiced we may be, it is impossible not to be deceived, so true are the effects of relief and perspective.

Fig. 295

This is the principle of the stereoscope. Fig. 294 shows the path of the rays of light in the instrument. At A is the drawing of the object seen with the left eye; at B that of the same object seen with the right. The rays from these images fall on two lenses *m* and *n*, and take, after having traversed them, the same direction as if they came from the point C; the object represented at A and B appears in relief at this spot.

The lenses *m* and *n* must impart exactly the same deviation to the rays, and they should therefore be exactly identical. Brewster at-

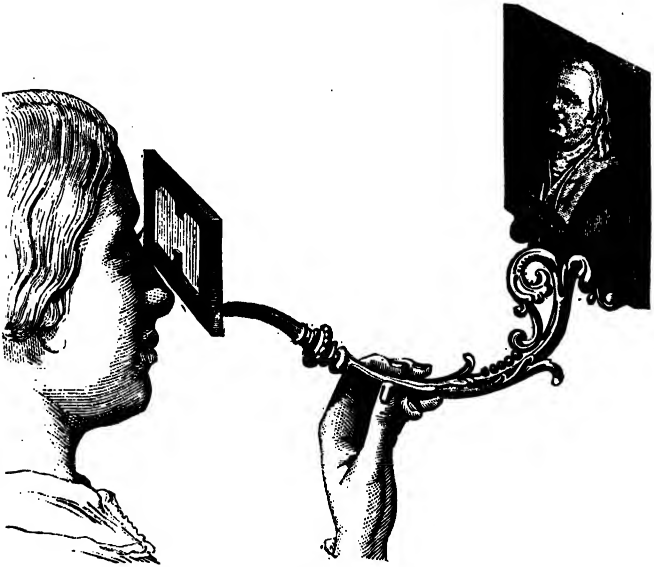

Fig. 296.

tained this result by cutting in two halves a double convex lens, and placing the right half in front of the left eye, and the left half in front of the right eye, as shown in fig. 294.

To produce the sensation of relief, the two dissimilar images at A and B should give from two different points of view so faithful a representation of the same object, that these separate views cannot be taken by the hand. And it is only practicable by means of photography. Fig. 295 represents two photographs of a statuette

of Franklin, taken at a slightly different angle. That of the left represents more of the full face, and must be looked at with the left eye; the other one is more in profile, and must be viewed with the right eye. These two views being placed in the stereoscope disappear for each observer, for then the two sensations special to each eye coalesce, and form a single image as represented in fig. 296, and the original appears so solid, with such perfect relief, that the imagination can with difficulty realise the fact that we are only concerned with a drawing on a plain surface.

BOOK VII.

ON MAGNETISM.

CHAPTER I.

PROPERTIES OF MAGNETS.

374. **Natural and artificial magnets.**—Natural magnet, or *loadstone*, is a mineral which has the property of attracting iron and a few other metals, especially nickel and cobalt. This mineral is an oxide of iron, that is, a compound of iron and oxygen like rust, from which it only differs in containing rather less oxygen.

Loadstone has another property, which is not less remarkable, namely, that when it is balanced on a pivot, or suspended to a thread, it points towards a certain direction of the horizon; and by this property this mysterious stone, which is of a dull brown colour, and has no lustre, deserves a place above the most valuable precious stones, for, like a new Ariadne's thread, it guides mariners in darkness, and enables them to steer with the same certainty on sea as on a travelled road.

This loadstone, or magnetic stone, was known to the ancients, who called it Lydian stone, or stone Magnesia; for it was first found near a village of this name in Lydia. And from the town of Magnesia the Greeks derived the name *magnes*, from which is derived the word magnetism, under which name philosophers understand the whole of the properties which magnets possess. Magnetic iron ore is very abundant in nature; it is met with in the older geological formations, especially in Sweden and Norway, where it is worked as an iron ore, and furnishes the best quality of iron.

Besides natural there are also *artificial* magnets, so-called from their being produced by art. They are usually made of steel. When steel is *tempered*, that is, when it is raised to a high temperature, and suddenly cooled by being immersed in cold water,

it acquires great hardness; and it is in virtue of this property that it becomes so valuable for cutting instruments. Steel has not naturally the power of attracting iron; but when it is tempered and made hard this property may be imparted to it by rubbing it with a powerful magnet; and it then becomes itself a magnet.

Artificial magnets have just the same properties as natural ones, but are far more powerful and convenient; they are, accordingly, generally used in experiments. They are sometimes made into bars a foot or two long, like those represented in fig. 297; some-

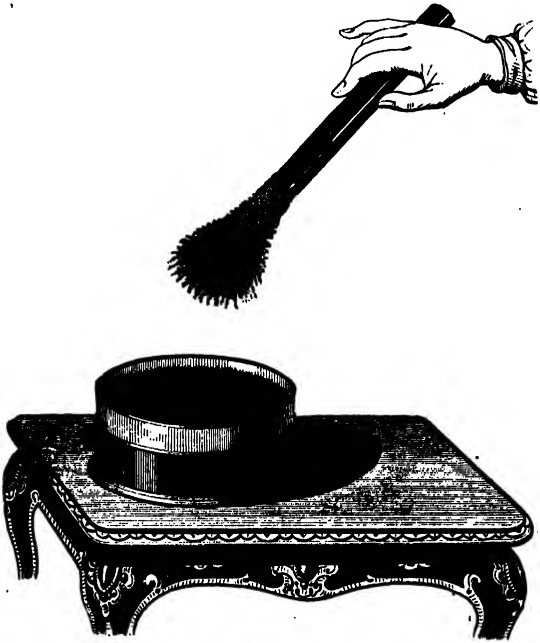

Fig. 297.

times in a horseshoe form (fig. 306); or lastly, if they are to be movable, they are cut in a thin plate in the shape of a lozenge as shown in fig. 297. A small agate cup is let into the centre in such a manner that the needle can rest on a vertical pivot and oscillate freely in a vertical plane. Thus arranged, the artificial magnet becomes a *magnetic needle.*

375. **Distribution of magnetic force in magnets.**—The force with which a magnet attracts iron is not everywhere the same. The greatest attraction is at the ends : it decreases rapidly from there towards the middle, where there is no attraction. For, if a magnetised bar is immersed in iron filings, when it is withdrawn the filings are seen to adhere to the end in long and compact filaments (fig. 297) ; but if the entire magnet is placed in the filings, not a particle adheres to the middle.

The two points near the ends where the attraction is most powerful are called the *poles* of the magnet, and the medial part, where there is no attraction, is called the *neutral line*. All magnets, natural or artificial, have each two poles and a neutral line. Sometimes, besides the two principal poles, there are observed intermediate poles, which are called *consequent points*. This arises

Fig. 298.

from some inequality in the temper of the steel, or in the manner in which the bar has been magnetised. We shall always assume that magnets have only two poles.

The action of magnets upon iron is exerted through all bodies which are not magnetic. Thus, a magnet is placed on a table and a piece of cardboard fixed upon it, and iron filings allowed to fall through a sieve. As the filings fall, acted upon by the two poles, they become arranged in long filaments, which group themselves along curved lines from one pole to the other; but above the

middle of the magnet no action is observed, and the filings are arranged as they would be upon any other substance.

376. **Laws of magnetic attraction and repulsion.**—When the two poles of a magnet are compared as to the action they exert upon iron, they seem to be completely identical; this identity is, however, only apparent; for, if to the same pole of a magnetic needle (fig. 299) the two poles of a bar magnet held in the hand be successively presented, the curious phenomenon is observed that, if the pole *a* of the needle is attracted by pole B of the bar, it is, on the contrary, repelled by the other pole of the latter; which

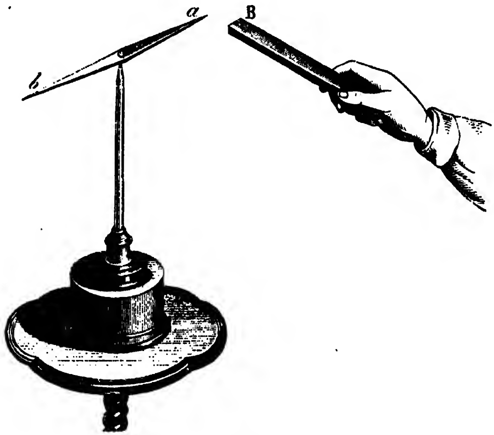

Fig. 299.

shows that the poles of the bar are not exactly identical, for one repels the pole *a*, while the other attracts it. The same difference may be ascertained to exist between the two poles of the needle *ab*; for if the same pole, B, of the bar be successively presented to the two ends of the movable needle, in one case there is repulsion, in the other attraction.

We shall presently see that a freely suspended magnet always sets with one pole pointing to the north, and the other towards the south. The end *pointing towards the north* is called in this country the *north pole*, and the other end is the *south pole*. The end of the magnetic needle pointing to the north is sometimes called the *marked end of the needle*.

Hence, in reference to magnetic attractions and repulsions the following law may be enunciated :

Poles of the same name repel, and poles of contrary name attract one another.

The opposite actions of the north and south poles may be shown by the following experiment :—A piece of iron, a key for example, is supported by a magnetised bar. A second magnetised bar of the same dimensions is then moved along the first, so that their poles are contrary. The key remains suspended so long as the two poles are at some distance, but when they are sufficiently near, the key drops just as if the bar which supported it had lost its magnetism. This, however, is not the case, for the key would be again supported if the first magnet were presented to it after the removal of the second bar.

The attraction which a magnet exerts upon iron is reciprocal, which is indeed a general principle of all attractions. It is easily verified by presenting a mass of iron to a movable magnet, when the latter is attracted.

377. **Hypothesis of two magnetic fluids.**—In order to explain the phenomena of magnetism, the existence of two hypothetical *magnetic fluids* has been assumed, each of which acts repulsively on itself, but attracts the other fluid. The fluid predominating at the north pole of the magnet is called the *north* or *boreal* fluid, and that at the south pole, the *south* or *austral* fluid. Sometimes the terms *positive* and *negative* are employed, corresponding to the north and south fluids.

It is assumed that, before magnetisation, these fluids are combined round each molecule, and mutually neutralise each other ; they can be separated by the influence of a force greater than that of their mutual attraction, and can arrange themselves round the molecules to which they are attached, but cannot be removed from them.

The hypothesis of the two fluids is convenient in explaining magnetic phenomena, and will be adhered to in what follows. But it must not be regarded as anything more than an hypothesis, and it will afterwards be shown that magnetic phenomena appear to result from electrical currents, circulating in magnetic bodies ; a mode of view which connects the theory of magnetism with that of electricity.

378. **Influence of magnets upon magnetic substances.**—Magnetic substances are substances containing the two magnetic fluids,

but in the neutral state, that is to say, holding each other in check by their reciprocal action: such substances are iron, steel, nickel, and cobalt. Magnets also contain the two fluids, but there is between them and magnetic substances this difference: that in magnets the two fluids are separated, and each produces a separate effect; while in magnetic substances the fluids are combined and produce no effect.

A magnetic substance is readily distinguished from a magnet. The former has no poles; if successively presented to the two ends of a magnetic needle, *ab* (fig. 299), it will attract both ends equally, while one end of a magnet would attract the one, but repel the other end of the needle. Magnetic substances also have no action on each other, while magnets attract or repel each other, according as unlike or like poles are presented.

When a magnetic substance is placed in contact with the poles of a magnet, the north pole, for instance, this acting attractively on the south fluid of the substance, and repelling the north fluid, it follows that in this body a separation of the two fluids is effected, or, in other words, a true magnet is produced. For, if any piece of soft iron, an iron ring, for example, be presented to a magnetised bar, not merely is this ring supported, but it acquires the property of supporting the second; then this second a third, and so forth. Remove the bar, and the invisible link which unites this marvellous chain is broken, and the rings separate.

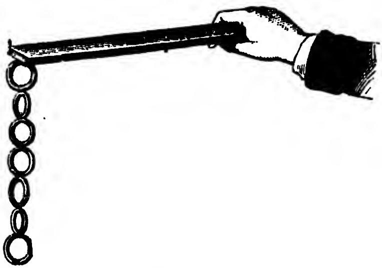

Fig. 300.

This action in virtue of which a magnet can develope magnetism in iron, is called *magnetic induction* or *influence*, and it can take place without actual contact between the magnet and the iron, as is seen in the following experiment. A bar of soft iron is held with one end near a magnetic needle. If now the north pole of a magnet be approached to the other end of the iron bar without touching it, the needle will be attracted or repelled, according as its south or north pole is near the bar. For the north pole of the magnet will develope south magnetism in the end of the bar nearest it, and, therefore, north magnetism at the other end, which would thus attract the south, but repel the north end of the

needle. Obviously, if the other end of the magnet were brought near the iron, the opposite effects would be produced on the needle.

Magnetic induction explains the formation of the tufts of iron filings which become attached to the poles of magnets. The parts in contact with the magnet are converted into magnets; these act inductively on the adjacent parts, these again on the following ones, and so on, producing a filamentary arrangement of the filings.

379. **Coercive force.**—We have seen from the above experiments, that soft iron becomes instantaneously magnetised under the influence of a magnet, but that this magnetism is not permanent, and ceases when the magnet is removed. Steel likewise becomes magnetised by contact with a magnet, but the operation is effected with difficulty, and the more so as the steel is more highly tempered. Placed in contact with a magnet, a steel bar acquires magnetic properties very slowly, and, to make the magnetism complete, the steel must be rubbed with one of the poles. But this magnetism, once evoked in steel, is permanent, and does not disappear when the inducing force is removed.

These different effects in soft iron and steel are ascribed to a *coercive force*, which, in a magnetic substance, offers a resistance to the separation of the two fluids, but which also prevents their recombination when once separated. In steel this coercive force is very great, in soft iron it is very small or even quite absent. By oxidation, pressure, or torsion, a certain amount of coercive force may be imparted to soft iron, as will be explained under Magnetisation.

CHAPTER II.

TERRESTRIAL MAGNETISM. COMPASSES.

380. **Directive action of the earth on magnets.**—The power of attracting iron filings is not the only one which magnets present; they have also that of setting in a certain definite direction, when they can turn freely in a horizontal direction. Thus, when a magnetised needle is placed on a pivot on which it can move freely (fig. 301), it ultimately sets in a position which is more or less north and south. If removed from this position, it always returns to it after a certain number of oscillations

If instead of placing the needle on a pivot it be placed on a cork, and this in turn be floated on water, the disc will after a few oscillations come into a position which is the same as that it had on the pivot, that is, nearly due north and south. It is important in this second experiment to observe, that the disc only turns in a certain direction, and that, though free to make either a progressive or a retrograde motion, it remains in the middle of the vessel, and moves neither towards the north nor the south; hence the force which acts upon the middle is simply *directive*, and not attractive.

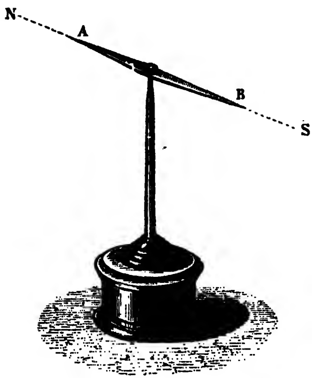

Fig. 301.

Analogous observations have been made in different parts of the globe, from which the earth has been compared to an immense magnet, whose poles are very near the terrestrial poles, and whose neutral line virtually coincides with the equator.

The polarity in the northern hemisphere is called the *northern* or *boreal* polarity, and that in the southern hemisphere the *southern* or *austral* polarity. In French works the end of the needle pointing north is called the *austral* or *southern* pole, and that pointing to the south the *boreal* or *northern* pole; a designation based on this hypothesis of a terrestrial magnet, and on the law that unlike magnetisms attract each other. In practice it will be found more convenient to use the English names, and call that end of the magnet which points to the north the north pole, and that which points to the south the south pole.

381. **Magnetic meridian. Declination.**—When a magnetic needle points towards the north, if we conceive an infinitely long straight line passing through its two poles, this line is what is called the *magnetic meridian* of the place. The direction of this line does not in general coincide with the geographical meridian of the place, which is the imaginary plane which passes through this place and through the earth's poles. The angle which the direction of the magnetic needle makes with the geographical

meridian is called the *declination* of the place. In other words, as the magnetic needle does not exactly point to the earth's north, the declination is the difference between this direction and the true north. Sometimes the north pole of the needle is to the west of the meridian, and sometimes it is to the east. In the former case the declination is said to be *easterly*, and in the latter case *westerly*.

The declination of the magnetic needle, which varies in different places, is at present west in Europe and in Africa, but east in Asia and in North and South America. It shows further considerable variations even in the same place.

Thus, at London the needle showed in 1580 an east declination of 11° 36′; in 1663 it was at zero; from that time it gradually tended towards the west, and reached its maximum declination of 24° 41′ in 1818; since then it has steadily diminished; it was 22° 30′ in 1850, and is now (1872) 19° 40′ W.

At Yarmouth and Dover the variation is about 40′ less than at London; at Hull and Southampton about 20′ greater; at Newcastle and Swansea about 1° 15′, and at Liverpool 1° 30′, at Edinburgh 2° 5′, and at Glasgow and Dublin about 2° 25′, greater than at London.

Besides these variations, which are called *secular variations*, the declination of the magnetic needle undergoes accidental variations, known as *perturbations* or *magnetic storms*; these are manifested during the occurrence of thunder storms, of volcanic eruptions, and during the appearance of aurora borealis. The effect of the aurora is felt at great distances. Auroras which are only visible in the north of Europe act on the needle even in these latitudes, where accidental variations of 20 have been observed. In polar regions the needle frequently oscillates several degrees; its irregularity on the day before the aurora borealis is a presage of the occurrence of this phenomenon.

382. **Mariner's compass.**—The magnetic action of the earth has received a most important application in the *mariner's compass*. This is a declination compass used in guiding the course of a ship. Fig. 302 represents it in about half its ordinary size. At the bottom of a wood or metal box is drawn a star or *rose*, with sixteen branches, representing the points of the compass. On the contour of the box is a graduated circle, the zero of which is on the line NS, which marks the direction from north to south. In the

centre of the box, finally, is a steel pivot, on which rests a very mobile magnetic needle.

When the geographical meridian is known, the declination is easily determined by means of the compass. It need only be directed until the line NS is exactly in the direction of the meridian of the place. The point at which the needle stops marks the declination. If, on the contrary, the declination is known, and the geographical meridian is desired, the compass is turned until the needle deviates from the line NS by a quantity equal to the declination, and in the same direction, that is to say, to the cast if

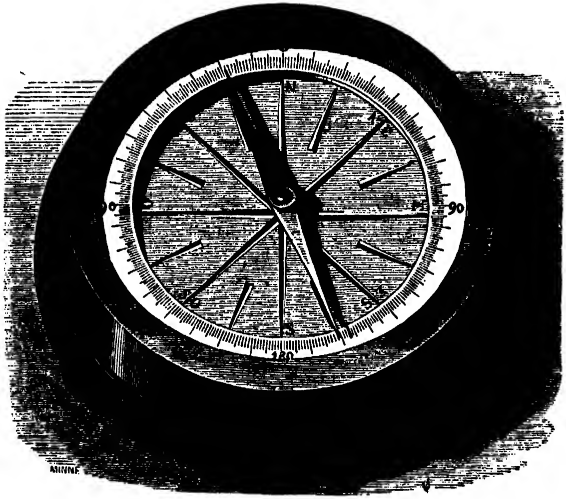

Fig. 302.

the declination is easterly, and to the west if it is westerly; the line NS prolonged represents the direction of the geographical meridian.

Neither the inventor of the compass, nor the exact time of its invention, is known. Guyot de Provins, a French poet of the twelfth-century, first mentions the use of the magnet in navigation, though it is probable that the Chinese long before this had used it. The ancient navigators, who were unacquainted with the compass, had only the sun or pole-star as a guide, and were accord-.

ingly compelled to keep constantly in sight of land, for fear of steering in a wrong direction when the sky was clouded. But guided by the indications of the compass, which are disturbed neither by darkness nor by the most violent tempests, they can pursue their true route by night as well as by day.

The compass is also used by miners to direct them in the excavation of subterranean passages.

383. **Inclination compass.**—When a steel needle supported on a vertical pivot, as represented in fig. 301, has been so accurately balanced that it is quite horizontal *before magnetisation*, it is observed that when it is magnetised it ceases to retain its horizontal position, and the north pole dips downward. When this phenomenon was first observed, it was ascribed to a defect of construction, but the regularity with which it occurred proved that it must be ascribed to the directive action of the earth.

In order to observe this phenomenon, the mode of suspension is modified, and it is fixed to a horizontal axis, so that it can move in a vertical plane, as represented in fig. 303. The angle it forms is read off on the divided circle.

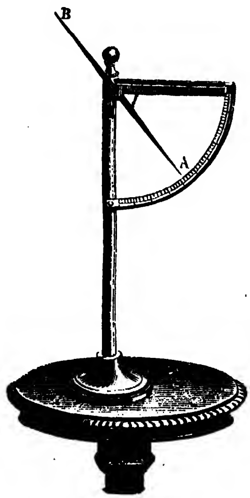

Fig. 303.

Thus arranged, the apparatus is called the *declination compass*, or *dipping needle*, and the angle which the needle makes with the horizon is called the *magnetic inclination* or *dip*.

The value of the dip, like that of the declination, differs in different localities. It is greatest in the polar regions, and decreases with the latitude towards the equator, where there is a series of points at which it is zero; that is, at which the needle is horizontal. The line joining these points is called the terrestrial *magnetic equator*. In London at the present time (1872) the dip is 67° 50′, reckoning from the horizontal line. In the southern hemisphere the inclination is again seen, but in a contrary direction; that is, the south pole of the needle dips below the horizontal line.

The *magnetic poles* are those places in which the dipping needle

stands vertical; that is, where the inclination is 90°. In 1830 the first of these, the terrestrial north pole, was found by Sir James Ross, in 96° 43′ west longitude and 70° north latitude. The same observer found in the South Sea, in 76° south latitude and 168° east longitude, that the inclination was 88° 37′. From this and other observations, it has been calculated that the position of the magnetic south pole was at that time in about 154° east longitude and 75½° south latitude.

Lines connecting places in which the dipping needle makes equal angles are called *isoclinic lines.*

The inclination is subject to secular variations, like the declination. At Paris, in 1671, the inclination was 75°; since then it has been continually decreasing, and in 1859 was 66° 14′. In London also the dip has continually diminished since 1720 by about 2·6′ per annum. In 1821 it was 70° 3′; in 1838, 69° 17′; in 1854 it was 68° 31′; in 1859 it was 68° 21′; it is now 67° 50′. It is also subject to slight annual and diurnal variations; being, according to Hanstein, about 15′ greater in summer than in winter, and 4′ or 5′ greater before noon than after.

CHAPTER III.

METHODS OF MAGNETISATION.

384. **Magnetisation by the influence of the earth.**—To magnetise a substance is to impart to it the magnetic properties of attracting particles of iron, and of turning towards the north. Magnetisation can be produced slowly by the influence of the earth, or rapidly by rubbing with a magnet; or by means of electricity, in which case the magnetisation is instantaneous.

The magnetic action of the globe is powerful enough to act as a source of magnetisation. This may be illustrated by taking a tolerably thick iron wire, and placing it in the magnetic meridian, so that it makes an angle equal to the angle of dip. In this position the earth's magnetism, acting by induction on the iron wire, decomposes the two fluids, and converts the lower end into a north pole, and the upper into a south pole. Yet this magnetisation is very unstable, for if the wire be turned upside down, the

poles are inverted, for pure soft iron is destitute of coercive force. But, if while the bar is in the above position it be hammered, or if it be twisted, the pressure or the twisting it undergoes imparts to it a certain amount of coercive force, and it retains for some time the magnetisation evoked in it. If several wires thus magnetised are united so that poles of the same name are together, a tolerably powerful magnet is obtained.

It is this magnetising action of the earth which developes the magnetism frequently observed in steel and iron instruments, such as fire-irons, railings, lightning conductors, lamp posts, etc., which remain for some time in a more or less inclined position. They become magnetised with their north pole downward, just as if placed

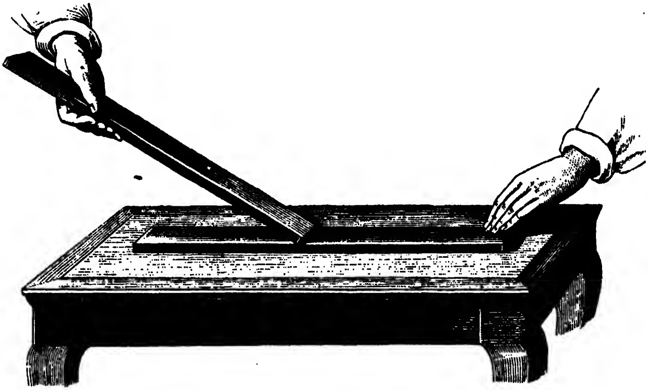

Fig. 304.

over the pole of a powerful magnet. The magnetism of native black oxide of iron has doubtless been produced by the same causes; the very different magnetic power of different specimens being partly attributable to the different positions of the veins of ore with regard to the line of dip. The ordinary irons of commerce are not quite pure, and possess a feeble coercive force; hence a feeble magnetic polarity is generally found to be possessed by the tools in a smith's shop. Cast-iron, too, has usually a great coercive force, and can be permanently magnetised.

The turnings, too, of wrought iron and of steel produced by the powerful lathes of our ironworks are found to be magnetised.

Magnetisation by magnets. In magnetising bar magnets, and

especially magnetic needles, the method generally adopted is to rub them with powerful magnets. This principle is applied in the methods of what are called *single*, *separate*, and *double touch.*

The method of single touch consists in moving the pole of a powerful magnet from one end to the other of the bar to be magnetised, and repeating this operation several times, always in the same direction. The neutral fluid is thus gradually decomposed throughout all the length of the bar, and that end of the bar which

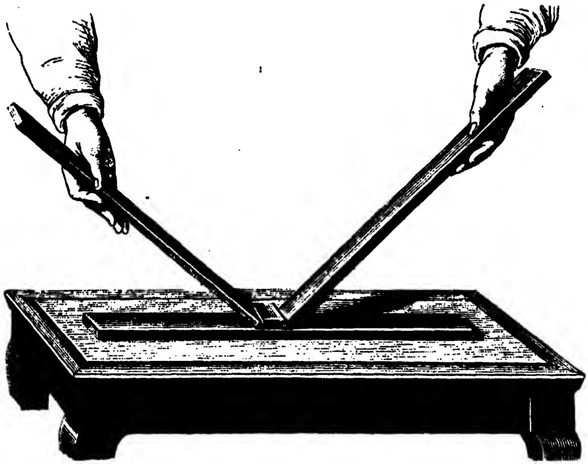

Fig. 305.

was touched last by the magnet is of opposite polarity to the end of the magnet by which it has been touched. This method only produces a feeble magnetic power, and is, accordingly, only used for small magnets. It has further the disadvantage of frequently developing consequent points.

In the method of separate touch the steel bar is rubbed separately with the contrary poles of two magnets, proceeding in opposite directions from the centre towards the ends.

Magnetisation by double touch. In this method the two magnets are placed with their poles opposite each other in the middle of the bar to be magnetised. But, instead of moving them in opposite directions towards the two ends, as in the method of separate touch, they are kept at a fixed distance by means of a piece of wood

placed between them (fig. 305), and are simultaneously moved first towards one end, then from this to the other end, repeating this operation several times, and finishing in the middle, taking care that each half of the bar receives the same number of frictions.

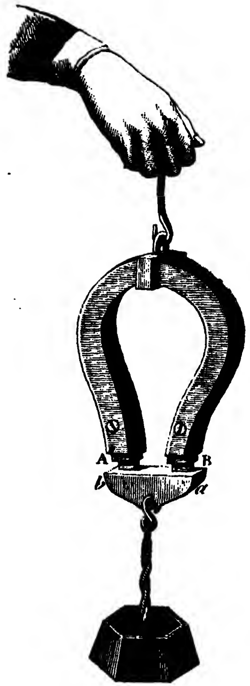

Fig. 306.

Magnetisation by means of electrical currents is the most powerful means of imparting magnetism, and is the one generally used for large magnets, whether bar or horse-shoe.

385. **Magnetic batteries. Armatures.**—Magnetic *battery*, or *magazine*, is the name given to a system of bars joined with their similar poles together. Sometimes the bars are straight, as represented in figs. 304 and 305, and sometimes they are curved, as in fig. 306, which represents a horse-shoe battery.

Magnets, whether natural or artificial, would soon lose their power if they were left to themselves, and they must therefore be provided with *armatures*. These names are given to pieces of soft iron which are placed in contact with the poles, such as the piece, *ab*, in fig. 306. The two poles of the magnet acting inductively on this piece produce in it at *a* a north pole, and at *b* a south pole, and these two poles thus produced react in turn upon the magnetised bar, and by preventing the recomposition of its two fluids cause it to retain its force. The piece, *ab*, is also called the *keeper*; to it is suspended the weight which the magnet is intended to support.

BOOK VIII.

FRICTIONAL ELECTRICITY.

CHAPTER I.

FUNDAMENTAL PRINCIPLES.

386. **Electricity. Its nature.**—Electricity is a powerful physical agent which manifests itself mainly by attractions and repulsions, but also by luminous and heating effects, by violent commotions, by chemical decompositions, and many other phenomena. Unlike gravity, it is not inherent in bodies, but is evoked in them by a variety of causes, among which are friction, pressure, chemical action, heat, and magnetism.

Thales, one of the Greek sages, 600 B.C., knew that when amber was rubbed with silk it acquired the property of attracting light bodies, such as feathers, pieces of straw, etc., and from the Greek form of this word (ἤλεκτρον, *electron*) the term *electricity* has been derived. Six centuries after it was found, Pliny, the celebrated Roman naturalist, writes, 'When the friction of the fingers has imparted to it heat and life, it attracts pieces of straw as a magnet attracts particles of iron.' This is nearly all the knowledge left by the ancients; and it was not until towards the end of the sixteenth century that Dr. Gilbert, physician to Queen Elizabeth, called attention to this property of amber, but showed that it was not limited to amber, but that other bodies, such as sulphur, wax, glass, etc., also acquired the property of attracting light bodies when they are rubbed or struck with flannel or with catskin.

To repeat this experiment, a glass rod, or a stick of sealing wax, or shellac, is held in the hand, and rubbed with a piece of flannel, or with the skin of a cat; it is then found that the parts rubbed have the property of attracting light bodies, such as pieces of silk, wool,

feathers, paper, bran, gold leaf, etc., which, after remaining a short time in contact, are again repelled. Not only have the substances thus rubbed the property of attracting light particles, but they also become luminous in the dark; they give sparks, and present a number of phenomena the cause of which is described under the general term *electricity*, the derivation of which has already been given.

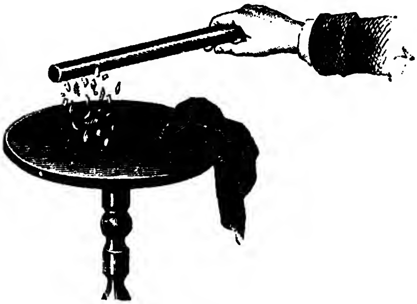

Fig. 307.

However slow the progress of the science of electricity in ancient times and in the middle ages, its progress during the eighteenth and nineteenth centuries has been extremely rapid. In the last seventy or eighty years, more especially, the new facts discovered have been so numerous and remarkable, their applications so curious and important, that electricity has been compared to a kind fairy, of whom it was only necessary to ask miracles to have them realised.

387. **Sources of electricity.**—The causes which develope electricity are numerous; they may be divided into mechanical, physical, and chemical sources.

The *mechanical sources* are friction, pressure, and cleavage. Thus, when a piece of sugar is broken in the dark, a feeble luminosity is seen, due to the electricity liberated. Cleavage is also a source of electricity; if a plate of mica be rapidly split in the dark, a slight phosphorescence is perceived.

The *physical sources* are variations in temperature: these effects are observed in some minerals, and more especially in tourmaline, which exhibits electrical properties when either heated or cooled.

Lastly, the *chemical sources* are the combinations and the decompositions of bodies. Thus, the metals, like zinc, iron, copper, when placed in an acid, unite with this to form salts. Now during these combinations considerable quantities of electricity are developed; the same is the case with chemical decomposition; that is, when compound bodies are separated into their elements.

The most powerful sources of electricity are friction and chemical action. We shall first of all investigate the influence of the first.

cause; and shall subsequently investigate the latter under the name of VOLTAIC ELECTRICITY.

388. **Electroscopes. Electrical pendulum.**—In order to ascertain whether bodies are electrified or not, instruments called *electroscopes* are used. The simplest of these, the *electric pendulum* (fig. 308), consists of a small pith ball attached by means of a silk thread to a brass rod resting on a glass support. To ascertain whether a body is electrified or not, it need only be presented to an electrical pendulum; in the first case there is attraction, while in the second case there is not. Yet the electrical pendulum would not be affected by a body very feebly charged with electricity.

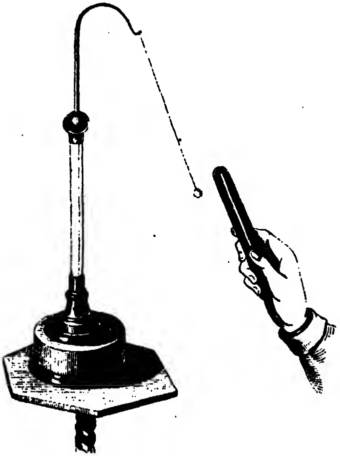

Fig. 308.

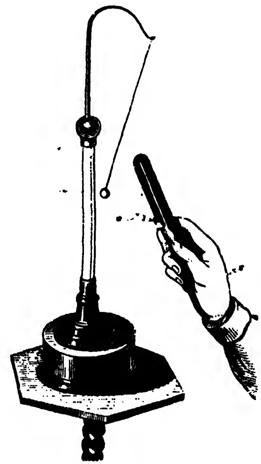

Fig. 309.

More complicated and more delicate apparatus must then be had recourse to, which will be afterwards described as *electrometers*.

389. **Distinction of the two kinds of electricity.**—If electricity be developed on a glass rod by friction with silk, and the rod be brought near an electrical pendulum (fig. 308), the ball will be attracted to the glass, and after momentary contact will be again repelled. By this contact the ball becomes electrified, and so long as the two bodies retain their electricity, repulsion follows when they are brought near each other. If a stick of sealing wax, electrified by friction with flannel or skin, be approached to another electrical pendulum, the same effects will be produced, the ball will

fly towards the wax, and after contact will be repelled. Two bodies, which have been charged with electricity, repel one another. But the electricities, respectively developed in the preceding cases, are not the same. If, after the pith ball has been touched with an electrified glass rod, an electrified stick of sealing wax, and then an electrified glass rod, be alternately approached to it, the pith ball will be *attracted* by the former and *repelled* by the latter. Similarly, if the pendulum be charged by contact with electrified sealing wax, it will be *repelled* when this is approached to it, but *attracted* by the approach of the electrically excited glass rod.

On experiments of this nature, Dufay first made the observation that there are two different electricities: the one developed by the friction of glass, the other by the friction of resin or shellac. To the first the name *vitreous* electricity is given; to the second the name *resinous* electricity.

390. **Hypothesis of two electrical fluids.**—Notwithstanding the great importance and interest of the numerous electrical phenomena we are still ignorant of their real cause. Various hypotheses have been made to account for them. The most satisfactory, perhaps, is that which was propounded by Symmer, an English physicist.

Symmer's theory assumes that every body contains an indefinite quantity of a subtile imponderable matter, which is called the *electrical fluid.* This fluid is formed by the union of two fluids—the *positive* and the *negative.* When they are combined they neutralise one another, and the body is then in the natural or neutral state. By friction, by chemical action, and by several other means, this neutral fluid may be decomposed and the two fluids separated, but one of them can never be excited without a simultaneous production of the other. There may, however, be a greater or less excess of the one or the other in any body, and it is then said to be electrified *positively* or *negatively.* The two fluids were formerly called *vitreous* and *resinous,* but these have given place to the terms *positive* and *negative* fluids, to which they respectively correspond, and which were first used by Franklin. This distinction is merely conventional; it is adopted for the sake of convenience, and there is no other reason why resinous electricity should not be called positive electricity.

Fluids of the same name repel one another, and fluids of opposite kinds attract each other. The fluids can circulate freely on the

surface of certain bodies, which are called conductors, but remain confined to certain parts of others, which are called nonconductors.

As has been already said, this theory is quite hypothetical; but its general adoption is justified by the convenient explanation which it gives of electrical phenomena.

391. **Laws of electrical attraction and repulsion.**—Adopting this two-fluid theory, the qualitative and quantitative laws of electrical attraction and repulsion may be stated as follows:

I. *Two bodies charged with the same electricity repel each other; two bodies charged with opposite electricities attract each other.*

II. *The repulsions or attractions between two electrified bodies are in the inverse ratio of the squares of their distance.* That is to say, that if two bodies be charged to a certain extent with electricity and the distance between them be increased to twice or thrice the original amount, the attraction or repulsion will be one-fourth or one-ninth the original amount.

III. *The distance remaining the same, the force of attraction or repulsion between two electrified bodies is directly as the product of the quantities of electricity, with which they are charged.* Thus if the quantity of electricity with which a body is charged be twice or thrice its original amount, it will have twice or three times the attractive or repulsive force.

These attractions and repulsions take place in virtue of the action which the two electricities exert on themselves, and not in virtue of their action on the particles of matter.

The first of these laws follows from the experiment described above (389); the second and third were first stated by Coulomb, and may be demonstrated by an apparatus which he devised, which is known as *Coulomb's balance.*

392. **Coulomb's balance.**—Represented in fig. 310, this apparatus consists of a cylindrical glass case closed at the top by a plate of the same material. In this is an aperture on which is a glass support, *d.* This is not rigidly fixed but can be turned round. At the top of this tube is a brass cap, consisting of two pieces, one, *b*, which is rigidly fixed to the tube, *d*, and the other fitting in the first like a socket, so that it can be turned by the button, *t*. On *k* is a scale *e*, graduated in 360 degrees, and turning with it; *b* is provided with a fixed index, *a*, which shows by how many degrees the disc is turned.

To the disc is fixed a very fine silver wire, to which is suspended a shellac thread, *p*, terminated at one end by a small disc of thin

metal foil, *n*. In the cover, A, near the edge, is a second aperture, through which can be passed a glass rod, *i*, with a wooden handle, *r*, at one end, and terminating in a brass ball, *m*. A scale of 360 degrees is fixed on the cage, opposite the zero of which is the ball, *m*.

In experimenting with this apparatus the air is dried by placing in the cage some chloride of calcium, which is a highly hygroscopic substance. To establish the second law, that electrical attractions vary inversely as the square of the distance, the disc, *e*, is first turned until its zero corresponds to the mark, *a*; the tube, *d*, and

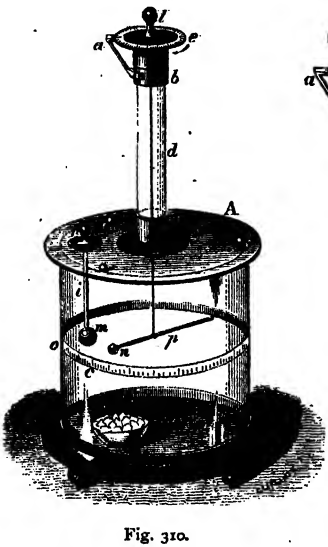

Fig. 310.

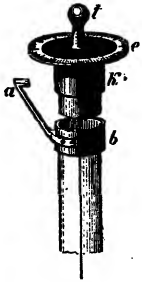

Fig. 311.

the whole cap, *k*, is slowly turned, until the silver thread being destitute of torsion, and the needle, *p*, at rest, the latter corresponds to the zero of the graduated circle: the knob, *m*, is in the same position, and thus presses against *n*. The knob, *m*, is then removed and electrified, and replaced in the apparatus, through the aperture, *r*. As soon as the electrified knob, *m*, touches *n*, the latter becomes electrified, and is repelled, and after a few oscillations comes to rest, at ten degrees for instance; the resistance of the wire to further torsion then just balances the force of repulsion.

As the arc of ten degrees is virtually the same as the chord, the number ten may be regarded as representing the distance of *m* and *n*. If the cap, *e*, is turned from left to right in the figure, it is found that, to reduce the distance to five degrees, it must be turned through thirty-five degrees. The wire is thus twisted through thirty-five degrees at the top and through five at the bottom; its total torsion is forty degrees, that is to say, four times as much as it was at first. Hence at the distance five the repulsion is four times as great as at the distance ten; for it is a known law, that the angle of torsion is proportional to the force of torsion. It may be shown in the same manner that, to make the distance from *m* to *n* one-third what it was, the total torsion must be ninety degrees, that is, nine times as great; the second law is thus thereby proved. In order to prove that attractions and repulsions between electrified bodies are proportional to the quantities of electricity which each of them possesses, the ball, *m*, is again electrified and placed in the cage; after contact it repels the disc, *n*, through a distance of, let us say, twelve degrees. The ball, *m*, is now withdrawn and placed in contact with a second brass ball of the same diameter, but insulated and unelectrified. As the electricity is equally distributed over both balls, the ball, *n*, loses half its electricity, and on again placing it in the cage, the repulsion which was twelve degrees is now only six, which verifies the third law.

393. **Conductors and nonconductors.**—When a glass rod, rubbed at one end, is brought near an electroscope, that part only will be electrified which has been rubbed; the other end will produce neither attraction nor repulsion. The same is the case with a rod of shellac or of sealing wax. In these bodies electricity does not pass from one part to another—they do not *conduct* electricity. Experiment shows, that when a metal has received electricity in any of its parts, the electricity instantly spreads throughout its entire surface. Metals are hence said to be good *conductors* of electricity.

Bodies have, accordingly, been divided into *conductors* and *nonconductors*. This distinction is not absolute, and we may advantageously consider bodies as offering a resistance to the passage of electricity which varies with the nature of the substance. Those bodies which offer little resistance are then conductors, and those which offer great resistance are nonconductors or insulators: electrical *conductivity* is thus the inverse of electrical *resistance*. We are to consider that between conductors and nonconductors there

is a *quantitative* and not a *qualitative* difference; there is no conductor so good but that it offers some resistance to the passage of electricity, nor is there any substance which insulates so completely but that it allows some electricity to pass. The transition from conductors to nonconductors is gradual, and no line of sharp demarcation can be drawn between them.

In this sense we are to understand the following table in which bodies are classed as *conductors, semiconductors,* and *nonconductors*; those bodies being conveniently designated as conductors which, when applied to a charged electroscope, discharge it almost instantaneously; semiconductors being those which discharge it in a short but measurable time, a few seconds, for instance; while nonconductors effect no discharge in the course of a minute.

Conductors.	*Semiconductors.*	*Nonconductors.*
Metals.	Alcohol and ether.	Dry oxides.
Graphite.	Powdered glass.	Caoutchouc.
Acids.	Dry wood.	Air and dry gases.
Water.		Dry paper.
Snow.		Silk.
Vegetables.		Diamond and precious stones.
Animals.		Glass.
		Sulphur.
		Resins.

394. **Insulating bodies. Common reservoir. Electrification of conductors.**—Bad conductors are called *insulators*, for they are used as supports for bodies in which electricity is to be retained. A conductor remains electrified only so long as it is surrounded by insulators. If this were not the case, as soon as the electrified body came in contact with the earth, which is a good conductor, the electricity would pass into the earth, and diffuse itself through its whole extent. On this account, the earth has been named the *common reservoir*. A body is insulated by being placed on a support with glass feet, or on a resinous cake, or by being suspended by silk threads. No bodies, however, insulate perfectly; all electrified bodies lose their electricity more or less rapidly by means of the supports on which they rest. Glass is always somewhat hygroscopic, and the aqueous vapour which condenses on it affords a passage for the electricity; the insulating power of glass is materially improved by coating it with shellac or copal varnish.

Dry air is a good insulator; but, when the air contains moisture, it conducts electricity, and this is the principal source of the loss of electricity.

It is from their great conductivity, that metals do not become electrified by friction. But if they are insulated, and then rubbed, they give good indications. This may be seen by the following experiment. A brass tube is provided with a glass handle, by which it is held, and then rubbed with silk or flannel. On approaching the metal to the pendulum, the pith ball will be attracted. If the metal is held in the hand electricity is indeed produced by friction, but it immediately passes through the body into the ground.

Electrifying by contact is due to conductibility. For when an insulated conductor in the neutral state is made to touch an electrified conductor, a portion of the latter passes instantaneously to the former. If the two bodies have the same surface, and the same shape, for instance, two spheres of the same diameter, the electricity is equally distributed on the two; but if the bodies differ in shape or surface the electricity is unequally distributed.

395. **Law of the development of electricity by friction.**—Whenever two bodies are rubbed together, the neutral fluid is decomposed. The two electricities are developed at the same time and in equal quantities—one body takes the positive, and the other the negative fluid. This may be proved by the following simple experiment devised by Faraday:—A small flannel cap provided with a silk thread is fitted on the end of a stout rod of shellac, and rubbed round a few times. When the cap is removed by means of a silk thread, and presented to a pith ball pendulum charged with positive electricity, the latter will be repelled, proving that the flannel is charged with positive electricity; while, if the shellac is presented to the pith ball, it will be attracted, showing that the shellac is charged with negative electricity. Both electricities are present in equal quantities; for if the rod be presented to the electroscope before removing the cap, no action is observed.

The electricity developed on a body by friction depends on the body rubbed. Thus glass becomes negatively electrified when rubbed with catskin, but positively when rubbed with silk. In the following list the substances are arranged in such an order, that each becomes positively electrified when rubbed with any of the bodies following, but negatively when rubbed with any of those which precede it:

1. Catskin.
2. Flannel.
3. Glass.
4. Silk.
5. The hand.
6. Wood.
7. Metals.
8. Caoutchouc.
9. Resin.
10. Sulphur.
11. Gutta percha.
12. Gun-cotton.

396. **Accumulation of electricity on the surface of bodies.**—Numerous experiments show that when a body is electrified, all the electrical fluid goes to the surface, where it is accumulated as an extremely thin layer, tending incessantly to escape, and flying off in short, when it is not retained by any obstacle.

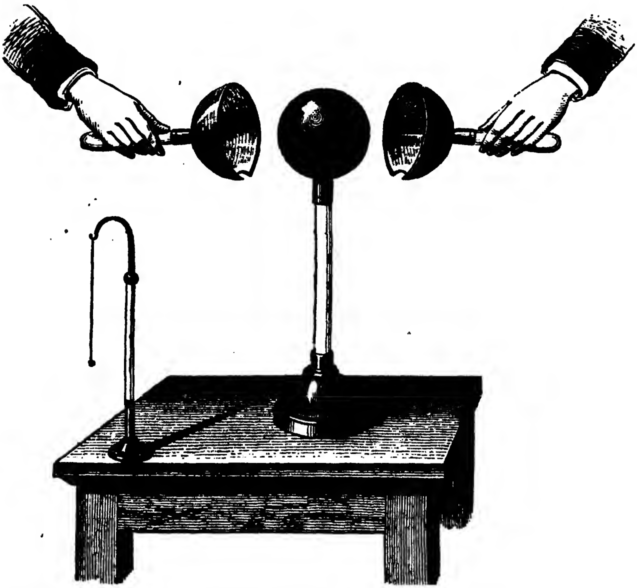

Fig. 312.

This may be demonstrated by the following experiment, which is due to Biot.

A hollow brass globe, fixed on an insulating support, is provided with two brass hemispherical envelopes which fit closely, and can be separated by glass handles. The interior is now electrified, and the two hemispheres brought in contact. On then rapidly removing

them (fig. 312) the coverings will be found to be electrified, while the sphere is in its natural condition, and indicates no electricity. Thus in removing, so to say, the surface of a body, all the free electricity it contained is also removed, which shows clearly that the electricity is on the surface. That electricity resides solely in the surface is further proved by the fact, that two metal spheres of the same diameter, but one of them solid and the other hollow, take the same charge of electricity when applied to the same source.

When accumulated on the surface of bodies, electricity tends to pass off to adjacent objects with an effort which is known as the *tension.* This increases with the quantity of electricity. So long as it does not exceed a certain limit, it is balanced by the resistance presented by the small conducting power of the air when it is dry. If the tension increases, this resistance is overcome, and the electricity springs off to an adjacent body with a sound, and in the form of a bright spark. In moist air the tension is always feeble, for the electricity passes away almost as rapidly as it is supplied, moisture being a good conductor of electricity. In very rarefied air, on the contrary, where there is little resistance, electricity passes off, presenting the appearance of a luminous glow.

397. **Influence of the shape of a body on the accumulation of electricity. Power of points.**—The manner in which electricity is distributed on the surface of a body varies with its shape. If it is spherical the amount is everywhere the same, which might indeed be predicted, and which may be readily confirmed by means of the *proof plane.* This is a small thin metal disc fixed at the end of a thin shellac rod. This is held in the hand, and successively applied to different parts of the electrified body, and after each contact is presented to an electrical pendulum. If the body is a sphere the attraction is in each case the same, which shows that the disc has taken the same charge of electricity from each point of the sphere, and, therefore, that the distribution of the electrical fluid is uniform.

This is no longer the case if the electrified body is more or less elongated, as, for instance, a kind of ovoid shape, as shown in fig. 313. In this case the proof plane is the more charged the nearer it is applied to the elongated end; and at this end itself most electricity is removed. This experiment shows that, in good conductors, electricity always tends to accumulate towards the most elongated parts towards the points. This accumulation produces a greater tension, which is sufficient to overcome the resistance of

the air, and allow electricity to escape. It is in fact observed, that metallic bodies provided with a point quickly lose their electricity, and, if the hand be held over such a point, a sort of wind or draught

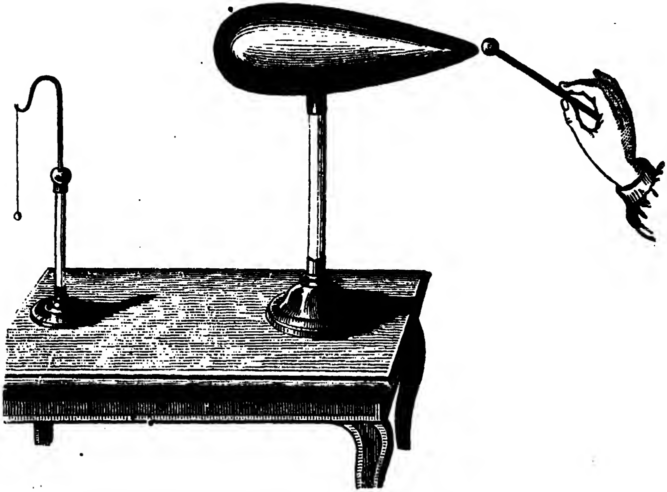

Fig. 313.

is felt. If this takes place in darkness, a kind of luminous brush appears on the top of the point.

This property of points, placed on electrified conductors, of allowing electricity to escape, has been called the *power of points;* and in electrical experiments we meet with numerous instances where it comes into play.

CHAPTER II.

ACTION OF ELECTRIFIED BODIES ON BODIES IN THE NATURAL STATE; INDUCED ELECTRICITY. ELECTRICAL MACHINES.

398. **Electricity by influence or induction.**—An insulated conductor, charged with either kind of electricity, acts on bodies in a natural state placed near it, in a manner analogous to that of the action of a magnet on soft iron, that is, it decomposes the

neutral fluid, attracting the opposite, and repelling the like kind of electricity. The action, which is a consequence of the attractions and repulsions of the two electricities, and which is exerted not only through air but also through insulating bodies like air, glass, resins, etc., is said to take place by *influence* or *induction.*

The phenomena of induction may be demonstrated by means of the experiment represented in fig. 314. On the right hand of the figure is the conductor of the electrical machine, which, as we shall afterwards see, is charged with positive electricity; on the left is a

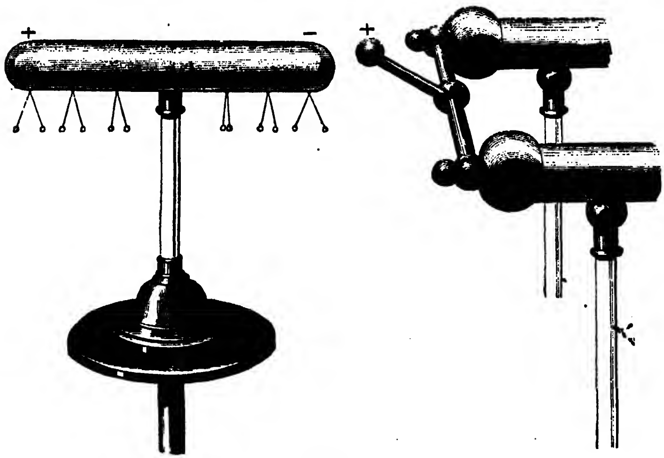

Fig. 314.

brass cylinder, insulated by being placed on a glass support, and provided with small pith ball pendulums, suspended by linen threads, which are conductors. When the cylinder of the machine is brought near this conductor, the pendulums are found to diverge but to unequal extents, the greatest divergence being met with at the ends. Near the middle the pith balls do not diverge at all; the electricity is, therefore, accumulated at the ends, and the middle is in the neutral state. If, moreover, a sealing-wax rod which has been rubbed with flannel be approached to the pendulums nearest the electrical machine, they will be repelled, showing that they are charged with the same electricity as the rubbed sealing wax, that is, negative electricity. If, in like manner, a glass rod, which has been rubbed with silk, be approached to the other end of the

cylinder, the pendulums are also repelled, which shows that they are charged with positive electricity. The electricities thus separated are equal in quantity, for if the machine is removed all the pendulums cease to diverge, since the two electricities have recombined, and the body is restored to the neutral state.

This *electrifying by influence*, or *induction* as it is called, which is produced by an electrified body or bodies in the neutral state, explains a host of phenomena. In order to explain all its effects, it is important to inquire what takes place when, in the above experiment, the insulated cylinder is placed for a short time in contact with the ground, while it is still under the influence of the machine. Suppose, for instance, the further end be placed in contact with the ground, the positive electricity will escape, while the negative remains held by the attraction of the opposite electricity of the machine. If now connection with the ground be interrupted and the cylinder be moved away from the influence of the machine, the pendulums will diverge, and, as can be easily verified, owing to their being charged with negative electricity. Even if the end nearest the machine be connected with the ground tbe result is still the same. The negative electricity does not pass into the ground; it is the positive which still escapes; the negative being attracted by the contrary electricity of the machine, on interrupting the communication with the earth, the cylinder remains charged with negative electricity.

Thus a body can be charged with electricity by induction as well as by conduction. But, in the latter case, the charging body loses part of its electricity, which remains unchanged in the former case. The electricity imparted by conduction is of the same kind as that of the electrified body, while that excited by induction is of the opposite kind. To impart electricity by conduction, the body must be quite insulated, while, in the case of induction, it must be in connection with the earth, at all events, momentaneously.

What has here been said has referred to the inductive action exerted on good conductors. Bad conductors are not so easily acted upon by induction, owing to the great resistance they present to the circulation of electricity, but, when once charged, the electric state is more permanent.

This is analogous to what is met with in magnetism; a magnet instantaneously evokes magnetism in a piece of soft iron; but this is only temporary, and depends on the continued action of the magnet; a magnet magnetises steel with far greater difficulty, but this magnetism is permanent.

ELECTRICAL MACHINES.

399. **Ramsden's electrical machine.** — The first electrical machine was invented by Otto von Guericke, the inventor also of the air-pump. It consisted of a sphere of sulphur, which was turned on an axis by means of the hand, while the other, pressing

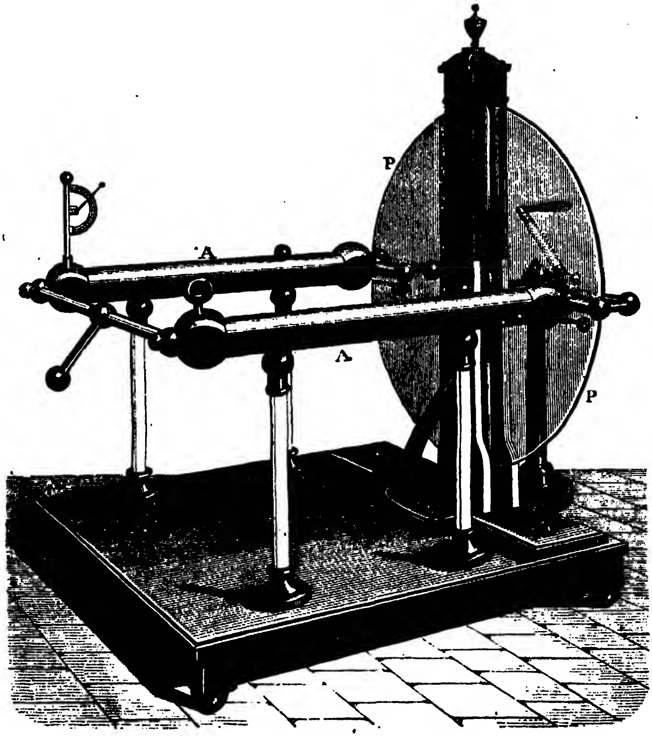

Fig. 315.

against it, served as a rubber. Resin was afterwards substituted for the sulphur, which, in turn, Hawksbee replaced by a glass cylinder. In all these cases the hand served as rubber; and Winckler, in 1740, first introduced cushions of horsehair covered

with silk as rubbers. At the same time, Bose collected electricity disengaged by friction, on an insulated cylinder of tin plate. Lastly, Ramsden, in 1760, replaced the glass cylinder by a circular glass plate, which was rubbed by cushions. The form which the machine has now is but a modification of Ramsden's original machine.

Between two wooden supports (fig. 315) a circular glass plate, P, about a yard in diameter, is suspended by an axis passing through the centre, and which is turned by means of a glass handle. The plate revolves between two sets of *cushions* or *rubbers*, I, I, of leather or of silk, one set above the axis and one below, which, by means of screws, can be pressed as tightly against the glass as may be desired, by which means the plate becomes electrified on both sides. The plate also passes between two brass rods shaped like a horse-shoe, and provided with a series of points in the sides opposite the glass, which are called the *combs*; these rods are fixed to larger metallic cylinders, C, which are called the *conductors*. The latter are insulated by being supported on glass feet, and are connected with each other by a smaller rod.

The action of the machine is founded on the excitation of electricity by friction, and on the action of induction. By friction with the rubbers, the glass becomes positively, and the rubbers negatively electrified. If now the rubbers were insulated, they would receive a certain charge of negative electricity which it would be impossible to exceed, for the tendency of the opposed electricities to reunite would be equal to the power of the friction to decompose the neutral fluid. But the rubbers communicate with the ground by means of bands of tinfoil, EE, fixed to the supports, and, consequently, as fast as the negative electricity is generated, it passes off. The positive electricity of the glass acts then by induction on the conductor, attracting the negative fluid. The conductors thus lose their negative electricity, and remain charged with positive fluid. The plate accordingly gives up nothing to the conductors; in fact, it only abstracts from them their negative fluid.

As thus described, the electrical machine yields only positive electricity; it may, however, be arranged so as to give negative electricity. For this purpose the four feet of the table are insulated by being placed on thick plates of resin, of glass, or of sulphur, and the conductors are connected with the ground by a metallic chain. This allows the electricity of the positive conductors to escape,

while the negative electricity of the rubbers accumulates on the supports and on the bands of tinfoil, EE.

400. **Measurement of the charge of the electrical machine. Quadrant electrometer.**—The amount of electrical charge, or electric tension, is measured by the *quadrant* or *Henley's electrometer*, which is represented in fig. 315 attached to the conductor. This is a small electric pendulum, consisting of a wooden rod, *d*, to which is attached an ivory or cardboard scale, *c* (fig. 315). In the centre of this is a small whalebone index, movable on an axis, and terminating in a pith ball, *a*. Being attached to the conductor, the index rises as the machine is charged, ceasing to rise when the limit is attained. When the rotation is discontinued the index falls rapidly if the air is moist; but in dry air it only falls slowly, showing, therefore, that the loss of electricity in the latter case is less than in the former.

Hence in moist and rainy weather all experiments with the electrical machine are difficult to perform. All parts of the apparatus must be carefully warmed by a charcoal chauffer, and the supports and plate must be rubbed with hot cloths.

The rubbers require great care both in their construction and in their preservation. They are commonly made of leather stuffed with horsehair. Before use they are coated either with powdered *aurum musivum* (sulphuret of tin), or graphite, or amalgam. The action of these substances is not very clearly understood. Some consider that it merely consists in promoting friction. Others again believe that a chemical action is produced, and assign in support of this view the peculiar smell noticed near the rubbers when the machine is worked. Amalgams, perhaps, promote most powerfully the disengagement of electricity. *Kienmayer's amalgam* is the best of them.

Whatever precautions be taken to avoid the loss of electricity, or however rapidly the machine is turned, it is impossible to exceed a certain limit. For as the electricity accumulates on the machine, its tension increases too, and very soon its tendency to escape exceeds the resistance offered by the air and the supports of the conductors. From this moment the loss of electricity equals the electricity disengaged by friction, and hence the tension can never exceed the limit it has attained, which is indicated by the electrometer remaining stationary although the rotation is continued.

If, moreover, the maximum effect is desired, the machine must not be placed too near the walls or the furniture; in short, away

from all objects on which it could act by induction, especially if these are angular, for it then continually withdraws the negative electricity and tends to revert to the neutral state. Thus if a point be presented to a machine in action, as represented in fig. 316, the electrometer falls, even though the point is at some distance. This is due to the fact that the positive electricity of the machine induces negative in the point, which flows out as fast as it is produced, and combining with the positive by means of which it was evoked, continually brings the machine back to the neutral state.

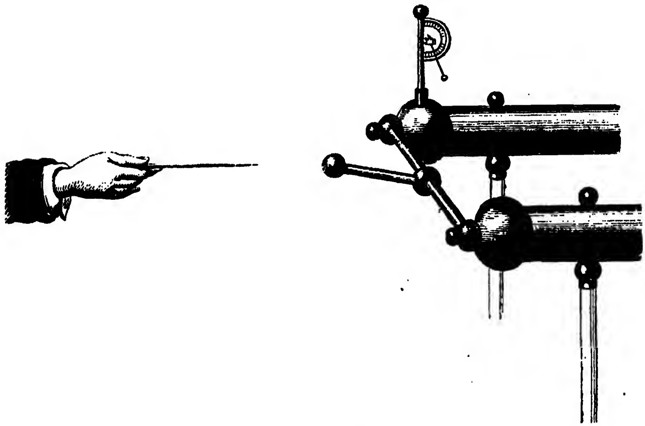

Fig. 316.

401. **Electrophorus.**—This is a very simple apparatus invented by Volta, and by means of which considerable quantities of electricity may be produced. It consists of a *cake* of resin, C (fig. 317), of about twelve inches diameter, and an inch thick, which is placed on a metallic surface, or very frequently fits in a wooden mould lined with tinfoil, which is called the *form*. Besides this, there is a wooden disc, of a diameter somewhat less than that of the cake, lined on its under surface with tinfoil, and provided with an insulating glass handle. This is called the *cover*. The mode of working this apparatus is as follows: All the parts of the apparatus having been well warmed, the cake, which is placed in the form, or rests on a metallic surface, is briskly flapped with a catskin, as shown in fig. 317, by which it becomes charged with negative electricity. The cover held by the insulating handle is then placed

on the cake. The negative electricity of the cake acting thus inductively on the cover attracts positive electricity to the lower surface, and repels negative to the upper. If now this upper surface be touched by the finger, as shown in fig. 318, the negative electricity passes out into the ground, and the disc only retains positive electricity. Now when the cover is raised by one hand by means of the insulating handle, and the other hand is brought near it, a smart spark passes, due to the recombination of the positive of the disc with the negative produced by its induction in the hand (fig. 319).

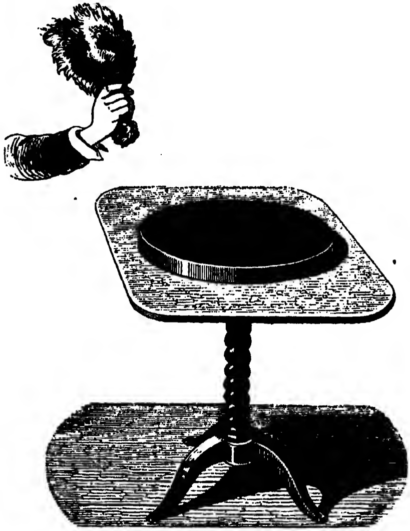

Fig. 317.

Replacing the disc upon the cake, this again exerts its inductive action, for it is such a bad conductor that the electricity does not pass off to the cover, and if the same operations be repeated, a succession of such sparks may be obtained even after the lapse of some time. The retention of electricity is greatly promoted by keeping the cake in the form, and placing the cover upon it, by which the access of air is hindered. Instead of a cake of resin, a disc of gutta percha, or vulcanised cloth, or vulcanite, may be substituted; and of course, if glass or any material which becomes

positively electrified by friction be used, the cover acquires a negative charge.


Fig. 318.

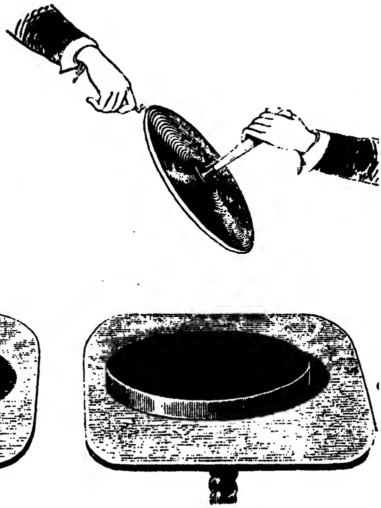
Fig. 319.

402. **Gold leaf electroscope.**—The *gold leaf electroscope*, also called *Bennett's electroscope* from the name of its inventor, is a small but delicate apparatus for ascertaining whether a body is electrified, and if so with what kind of electricity it is charged. It consists of a tubulated glass shade (fig. 320), the neck of which is closed by a cork. In this is fitted a brass rod terminating at the top in a knob and at the bottom in two strips of gold leaf. The neck, the cork, and the upper part of the shade are coated with a thick layer of sealing wax varnish, which is nothing more than a solution of sealing wax in spirits of wine. The object of this coating is to improve the insulating qualities of the glass. Glass is indeed a bad conductor, but it is very hygroscopic; that is, it readily attracts aqueous vapour from the air, and thus becomes coated with a layer of moisture which renders its surface a conductor. When covered with varnish this evil is removed, for varnishes, which are usually made of resin, are not at all hygroscopic.

The air in the inside is dried by quicklime, or by chloride of

calcium, and on the insides of the shade there are two strips of gold leaf communicating with the ground.

When the knob is touched with a body charged with either kind of electricity, the leaves diverge; usually, however, the apparatus is charged by induction thus:

If an electrified body, a stick of sealing wax rubbed with flannel, for instance, be brought near the knob, it will decompose the natural electricity of the system, attracting to the knob the fluid of the opposite kind and retaining it there, and repelling the electricity of the same kind to the gold leaves, which consequently diverge.

Fig. 320.

In this way, the presence of an electrical charge is ascertained, but not its quality.

To ascertain the kind of electricity the following method is pursued: If, while the instrument is under the influence of the body, which we will suppose has a negative charge, the knob be touched by the finger, the negative electricity decomposed in induction passes off into the ground, and the previously divergent leaves will collapse: there only remains positive electricity retained in the knob by induction from the sealing wax. If now the finger be

first removed, and then the electrified body, the positive electricity previously retained by the sealing wax will spread over the system, and cause the leaves to diverge with positive electricity. If now, while the system is charged with positive electricity, a positively electrified body, as, for example, an excited glass rod, be approached, the leaves will diverge more widely; for the electricity of the same kind will be repelled to the extremities. If, on the contrary, an excited shellac rod be presented, the leaves will tend to collapse, the fluid, with which they are charged, being attracted by the opposite electricity. Hence we may ascertain the kind of electricity, either by imparting to the electroscope electricity from the body under examination, and then bringing near it a rod charged with positive or negative electricity; or the electroscope may be charged with a known kind of electricity, and the electrified body in question brought near the electroscope.

It has been proposed to use the electroscope as an *electrometer*, or measurer of electricity, by measuring the angle of divergence of the leaves. This is done by placing behind them a graduated scale. There are, however, many objections to such a use, and it is rarely employed for this purpose.

CHAPTER III.

ELECTRICAL EXPERIMENTS.

403. **Electrical spark.**—One of the first experiments which is made by those who see an electrical machine at work for the first time is that of taking from it an electrical spark by bringing the hand near the conductor. The positive electricity of the conductor acting inductively on the neutral fluid of the body, decomposes it, repelling the positive and attracting the negative fluid. When the tension of the opposed electricities is sufficiently great to overcome the resistance of the air, they recombine with a smart crack and a spark. The spark is instantaneous, and is accompanied by a sharp prickly sensation, more especially with a powerful machine. Its shape varies. When it strikes at a short distance, it is rectilinear, as seen in fig. 321. Beyond two or three inches in length, the spark becomes irregular, and has the form of a sinuous curve

with branches (fig. 322). If the discharge is very powerful, the spark takes a zigzag shape (fig. 323). These two latter appearances are seen in the lightning discharge.

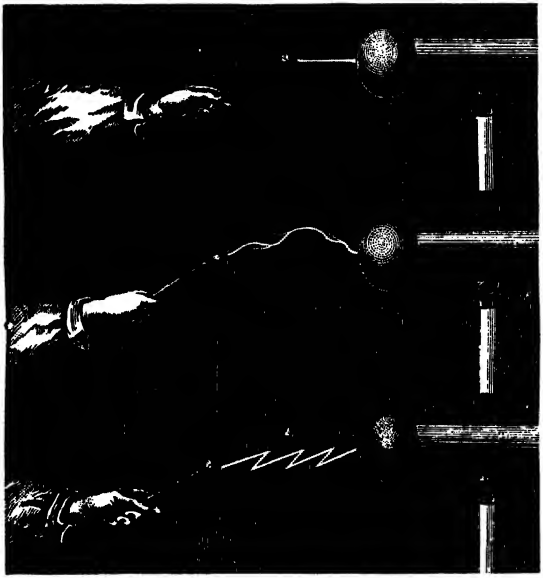

Fig. 321.

Fig. 322.

Fig. 323.

404. **Insulating stool.**—A spark may be taken from the human body by the aid of the *insulating stool,* which is simply a low stool with stout glass legs. The person standing on this stool touches the prime conductor, and as the human body is a good conductor, the electrical fluid is distributed over its surface as over an ordinary insulated metallic conductor (fig. 324). The hair diverges in consequence of repulsion, a peculiar sensation is felt on the face, and if another person, standing on the ground, presents his hand to any part of the body, a smart crack with a pricking sensation is produced.

405. **Electrical chimes.**—*The electrical chimes* is a bell work which is worked by electrical attraction and repulsion. It consists of three metal bells suspended to a horizontal brass rod, *m*, which is connected with the electrical machine (fig. 325). The two bells, *b*

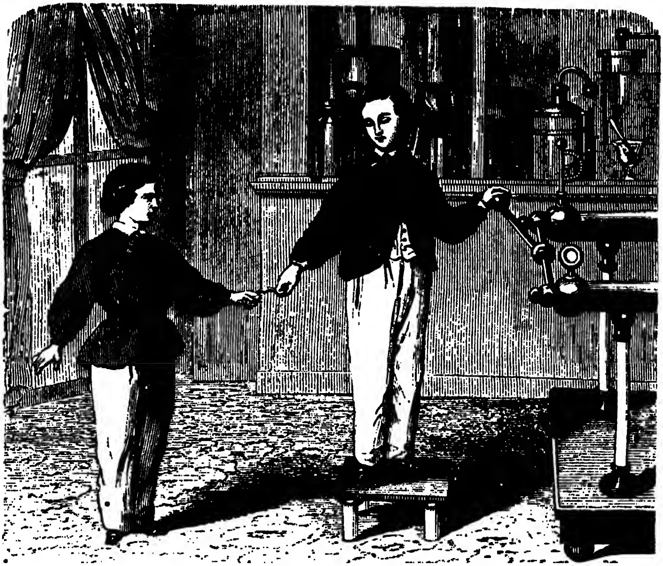

Fig. 324.

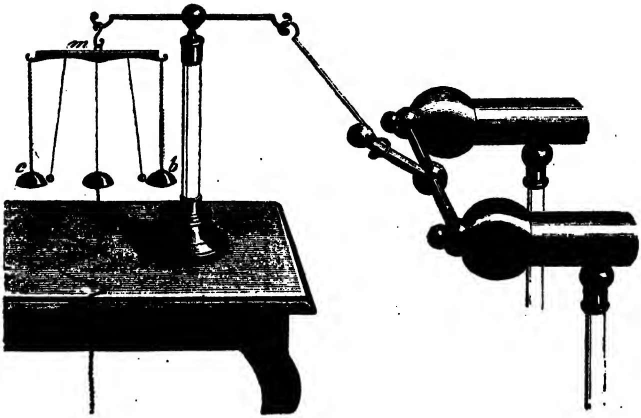

Fig. 325.

and *c*, are suspended by light metal chains; the middle one is suspended by silk, and is moreover connected with the ground by a chain. Between the bells are two small hollow copper balls suspended by silk threads to which they are attached. When the machine is worked these small copper balls are attracted by the electricity which passes to the bells, *b* and *c*, and strike against them; but being at once repelled they strike against the middle bell to which they give up their electricity, which thus passes into the ground. They are then again attracted, again repelled, and so on as long as the machine is at work.

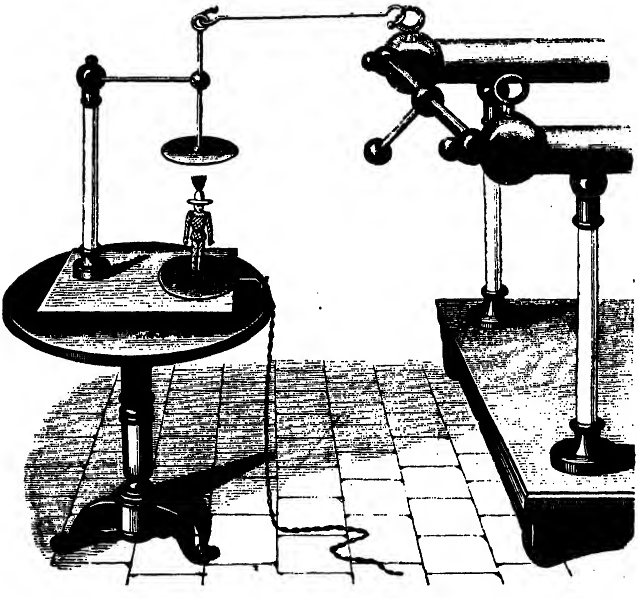

Fig. 326.

406. **Dancing puppets.**—This, like the chimes, is an application of the attractions and repulsions of electrified bodies. It consists in placing a small, very light figure of pith, loaded at the feet, between two metal discs, one connected with the ground and the other with the electrical machine (fig. 326). As soon as this latter becomes charged, the small puppet is successively attracted and

repelled from one to the other disc, as if it executed of its own proper action a series of jumps.

407. **Electrical whirl or vane.**—The electrical *whirl* or *vane* consists of four to six wires, terminating in points, all bent in the same direction, and fixed in a central cap, which rotates on a pivot (fig. 327). When the apparatus is placed on the conductor, and the machine worked, the whirl begins to revolve in a direction opposite that of the points. This motion is not analogous to that of the hydraulic tourniquet (78). It is not caused by a flow of material fluid, but is owing to a repulsion between the electricity of the points and that which they impart to the air by conduction. The electrical fluid, being accumulated on the points in a high state of tension, passes into the air, and imparting thus a charge of electricity, repels this electricity while it is itself repelled. That this is the case, is evident from the fact that, on approaching the hand to the whirl while in motion, a slight draught is felt, due to the movement of the electrified air; while in vacuo the apparatus does not act at all. This draught or wind is known as the electrical *aura.*

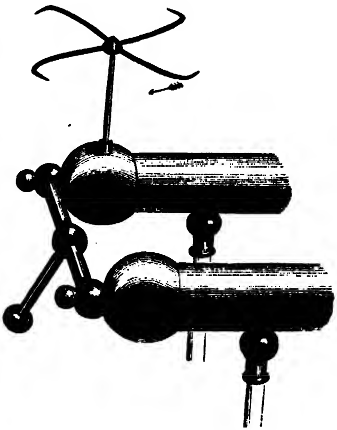

Fig. 327.

When the electricity thus escapes by a point, the electrified air is repelled so strongly as not only to be perceptible to the hand, but also to engender a current strong enough to blow out a candle. The same effect is produced by placing a taper on the conductor, and bringing near it a pointed wire held in the hand. The current rises, in this case, from the contrary fluid, which escapes by the point under the influence of the machine.

The *electrical orrery* and the *electrical inclined plane* are analogous to these pieces of apparatus.

408. **Electric egg.**—The influence of the pressure of the air, or rather of its nonconductivity, on the electric light, may be studied by means of the *electric egg.* This consists of an ellipsoidal glass

vessel (fig. 328), with metallic caps at each end. The lower cap is provided with a stopcock, so that it can be screwed into an air-pump, and also into a heavy metallic foot. The upper metallic rod moves up and down in a leather stuffing box; the lower one is fixed to the cap. An almost complete vacuum having been made, the stopcock is turned, and the vessel screwed into its foot; the upper part is then connected with a powerful electrical machine, and the lower one with the ground. On working the machine, the globe becomes filled with a feeble violet light continuous from one

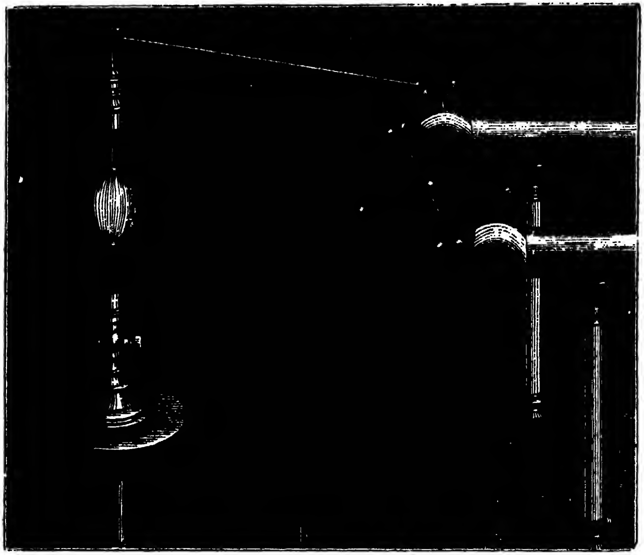

Fig. 328.

end to the other, and resulting from the recomposition of the positive fluid of the upper cap with the negative of the lower. If the air be gradually allowed to enter by opening the stopcock, the tension increases with the resistance, and the light which appears white and brilliant is now only seen as an ordinary spark.

409. **Magic pane.**—The magic pane consists of a glass plate, one side of which is covered with several folds of tinfoil, arranged so as to form a series of metallic bands, arranged parallel and close

to each other. The pane is supported vertically by two glass supports, and the upper end of the tinfoil is connected with the electrical machine by a conductor, and the lower one with the ground by a chain. In this condition, if the machine be worked, the elec-

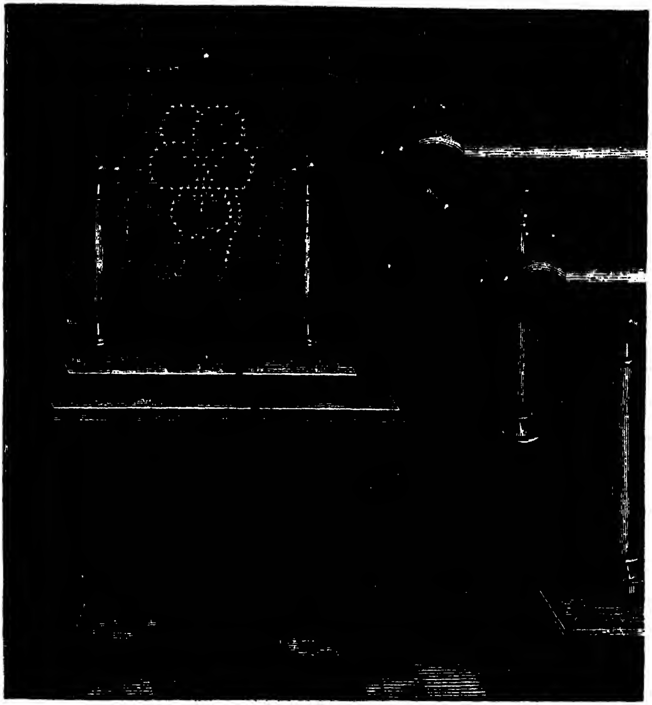

Fig. 329.

tricity will pass into the ground by the tinfoil, without any interruption; but if a series of breaks are made in the tinfoil by cutting it away with a penknife, a spark appears at each break; and if these breaks be so arranged as to represent a given object, a flower, or a monument, or words, these objects are reproduced in lines of fire when the electrical machine is set to work. This experiment is really due to the prodigious velocity of electricity, which is not less than about 190,000 miles in a second. Hence, in the above experi-

ment, although the sparks are really successive, they follow each other with such rapidity as to seem continuous.

410. **Luminous globe and tube.**—The *luminous globe* is a glass globe lined on the inside with a series of small lozenges of tinfoil placed very near each other without actually touching. The

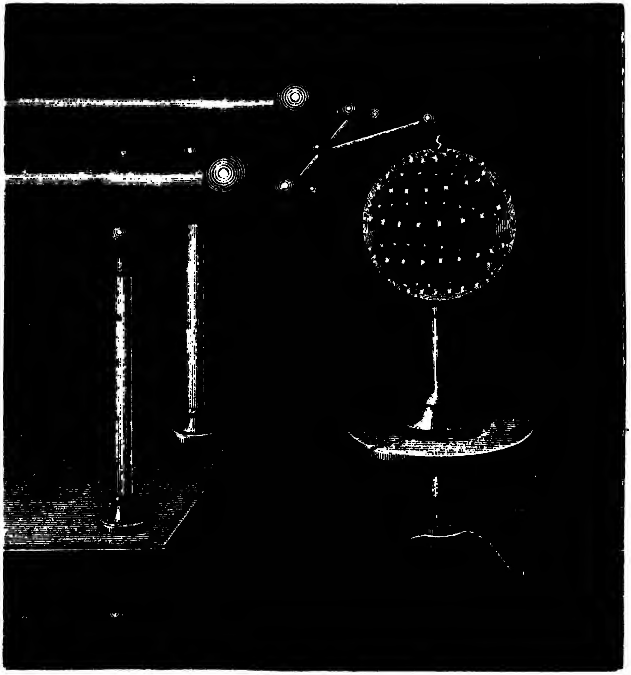

Fig. 330.

first plate is connected with an electrical machine at work, and the last with the ground, upon which a series of bright sparks appears at each break in the metallic conductor (fig. 330).

If the small metal plates are arranged inside a spiral glass lustre from one end to the other, this arrangement forms a luminous tube.

411. **Volta's cannon.**—This is not merely interesting as an experiment, but also as demonstrating an important fact, namely, that

the electrical spark can establish chemical action. Thus, water is formed of two gases, hydrogen and oxygen, in the ratio of one volume of the latter to two volumes of the former. Now, when an electrical spark is passed through a mixture of these two gases, they combine in their proportions, and form water. This combination is, moreover,

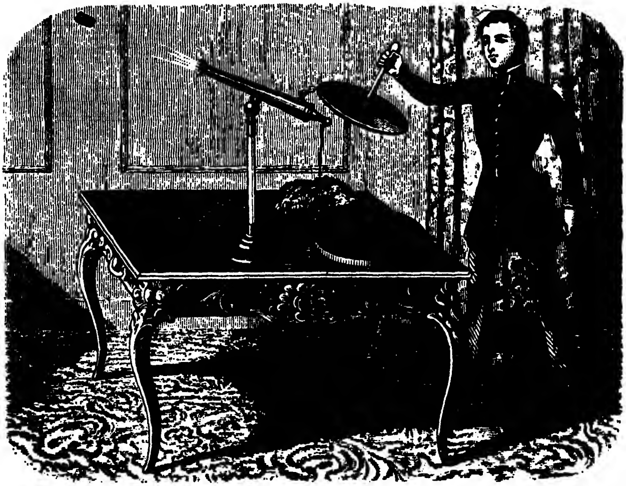

Fig. 331.

attended by a bright flash of light and a loud report, the latter being due to the expansive force of aqueous vapour, due to the high temperature produced by the combination.

On this property which mixtures have of detonating by the electrical spark, Volta's cannon, represented in fig 331, is constructed. It is a small brass cannon resting on an insulating support. In the touchhole is a small glass tube, and in this a brass wire with a small knob at each end; one of which knobs is on the outside, and the other very near the inside of the cannon, but not touching it. Having introduced a mixture of two parts of hydrogen and one of oxygen, the cannon is closed by a cork, and is connected with the ground by a metal chain. If then the charged disc of the electrophorus be approached, a spark passes to the small knob, and at the same time inside the cannon. This latter causes the two gases to combine with a violent explosion, which drives out the cork.

CHAPTER IV.

CONDENSATION OF ELECTRICITY.

412. **Electrical condensers.**—Condensers are apparatus by which electricity may be accumulated. Their shape is greatly varied, but they are all composed essentially of two insulated conductors separated by a non-conductor, and their working is an application of the action of induction. Epinus's condenser consists of two metal plates, A and B, insulated by being supported on glass legs (fig. 332); between them is a pane of ordinary glass, of somewhat larger diameter than that of the plates, A and B, which

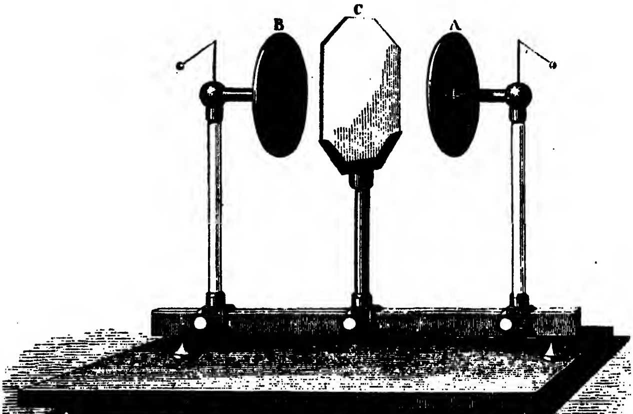

Fig. 332.

are about six inches in diameter. The legs can be moved along a support, and fixed in any position.

In explaining the action of the condenser, it will be convenient to call that side of the metal plate nearest the glass the *anterior*, and the other the *posterior*, side. And first let A be at such a distance from B as to be out of the sphere of its action. The plate B, which

is then connected with the conductor of the electrical machine, takes its maximum charge, which is distributed equally on its two faces, and the pendulum diverges widely. If the connection with the

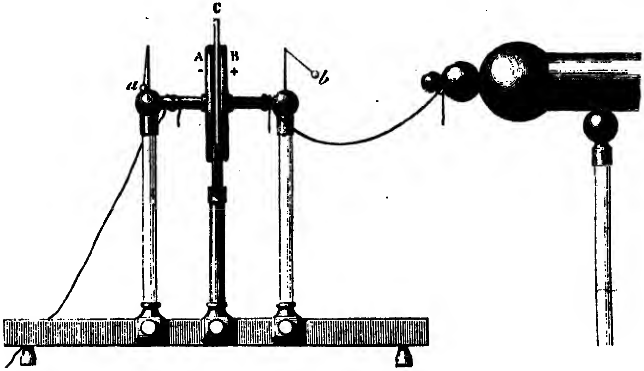

Fig. 333.

machine be interrupted, nothing would be changed; but if the plate, A, be slowly approached, its neutral fluid being decomposed by the influence of B, the negative is accumulated on its anterior face, *n* (fig. 334), and the positive passes into the ground. But as the negative electricity of the plate, A, reacts in its turn on the positive of the plate, B, the latter fluid ceases to be equally distributed on both faces, and is accumulated on its anterior face, *m*. The posterior face, *p*, having thus lost a portion of its electricity, its tension has diminished, and is no longer equal to that of the machine, and the pendulum, *b*, diverges less widely. Hence B can receive a fresh quantity

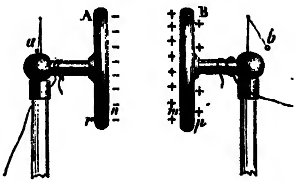

Fig. 334.

from the machine, which acting as just described decomposes by induction a second quantity of neutral fluid on the plate, A. There is then a new accumulation of negative fluid on the face, *n*, and consequently of positive fluid on *m*. But each time the machine gives off electricity to the plate, only a part of this passes to the face, *m*, the other remaining on the face, *p*; the

tension here, therefore, continues to increase until it equals that of the machine. From this moment equilibrium is established, and a limit to the charge attained, which cannot be exceeded. The quantity of electricity accumulated now on the two faces, *m* and *n*, is very considerable, and yet the pendulum diverges just as much as it did when A was absent and no more ; in fact, the tension at *p* is just what it was then, namely, that of the machine.

The accumulation of electricity in condensers was formerly explained by saying that the electricity of the *condensing* plate, A, *neutralised* the contrary electricity of the *collecting* plate, and it was because the electricity on this latter was then *dissimulated* or *latent* that it could receive a fresh supply. But from what has been said, it is unnecessary to recur to any special hypothesis as to the state of electricity to explain the theory of condensers.

When the condenser is charged, that is, when the opposite electricities are accumulated on the anterior faces, connection with the ground is broken by raising the wires. The plate A is charged with negative electricity, but simply on its anterior face (fig. 333), the other side being neutral. The plate B, on the contrary, is electrified on both sides, but unequally; the accumulation is only on its anterior face, while on the posterior, *p*, the tension is simply equal to that of the machine at the moment the connections are interrupted. In fact the pendulum, *b*, diverges and *a* remains vertical. But, if the two plates are removed, the two pendulums diverge (fig. 334), which is owing to the circumstance that, as the plates no longer act on each other, the positive fluid is equally distributed on the two faces of the plate B, and the negative on those of the plate A.

413. **Slow discharge and instantaneous discharge.**—While the plates, A and B, are in contact with the glass (fig. 333), and the connections interrupted, the condenser may be discharged, that is, restored to the neutral state, in two ways; either by a slow or by an instantaneous discharge. To discharge it slowly the plate B, that is, the one containing an excess of electricity, is touched with the finger; a spark passes, all the electricity on *p* escapes into the ground, the pendulum, *b*, falls, but *a* diverges. For B having lost part of its electricity only retains on the face, *m*, that held by the inductive influence of the negative on A. But the quantity thus retained at B is less than that on A: this has free electricity, which makes the pendulum, *a*, diverge; and, if it now be touched, a spark passes, the pendulum, *a*, sinks while *b* rises, and so on by continuing

to touch alternately the two plates. The discharge only takes place slowly; in very dry air it may require several hours. If the plate, A, were touched first, no electricity would be removed, for all it has is retained by that of the plate, B. To remove the total quantity of electricity by the method of alternate contacts, an infinite number of such contacts would theoretically be required.

To obtain an instantaneous discharge one hand may be placed on one plate, and the second touched with the other hand; a violent shock is then felt, far more violent than that produced by the electrical machine. To avoid this a *discharging rod* is used, which consists of two bent stout brass wires terminating in knobs and joined by a hinge. If this be held in the hand as represented in fig. 336, and one knob be applied to one plate of the condenser while the arc is bent, so that the second touches the other plate. Just as this is on the point of touching a spark passes, which is due to the reunion of the two electricities accumulated on the condenser; no shock is felt, for the recombination does not take place through the arms and body of the experimenter, but through the metallic arc, which is a far better conductor.

414. **Limit of the charge of condensers.**—The quantity of electricity which can be accumulated on each plate is, other things being equal, proportional to the tension of the electricity on the conductor, and to the surface of the plates: it decreases as the insulating plate is thicker, and it differs with the specific inductive capacity of the substance. Two causes limit the quantity of electricity which can be accumulated. First, that the electric tension of the collecting plates gradually increases, and ultimately equals that of the machine, which cannot, therefore, impart any free electricity. The second cause is the imperfect resistance which the insulating plate offers to the recombination of the two opposite electricities; for when the force which impels the two fluids to recombine exceeds the resistance offered by the insulating plate, it is perforated, and the contrary fluids unite.

415. **The Leyden jar.**—The *Leyden jar*, or *flask*, so called from the town of Leyden, where it was invented, is essentially a condenser, only differing in shape from that which has been described. It was accidentally discovered in 1746 by Muschenbrock, a Dutch physician. Wishing to electrify water contained in a flask he passed through the cork a wire which he presented to the conductor of the machine. After holding it in this position for some time he was on the point of removing the rod with the other hand when he

received in the arms and breast a shock so violent that it was two days before he recovered from the effects; and writing to his friend Reaumur he said, he would not repeat the experiment for the whole kingdom of France.

The fact thus discovered caused probably a greater sensation throughout Europe than any other one has ever done. It was repeated innumerable times, and the apparatus, after successive modifications and improvements, acquired its present form. It is not difficult to see that the above experiment is a case of condensation. The liquid in the flask acts as a collector, the hand acts as a condensing plate, and the insulating plate is formed by the material of the flask itself.

The ordinary form of the Leyden jar consists of a glass bottle or

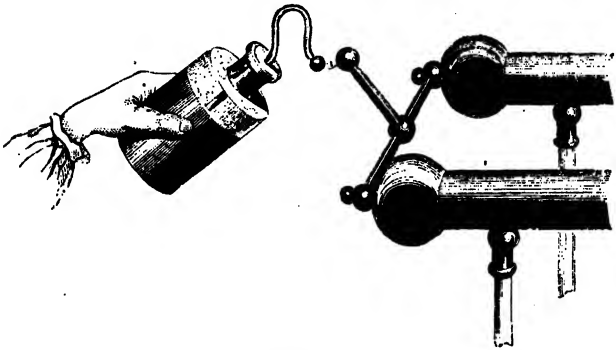

Fig. 335.

any convenient size, the interior of which is either coated with tinfoil or filled with thin leaves of copper, or with gold leaf. Up to a certain distance from the neck the outside is coated with tinfoil. The neck is provided with a cork, through which passes a brass rod, which terminates at one end in a knob, and communicates with the metal in the interior. The metallic coatings are called respectively the *internal* and *external armatures* or *coatings*. Like the condenser, the jar is charged by connecting one of the armatures with the ground, and the other with the source of electricity. When it is held in the hand by the external coating, and the knob presented to the conductor of the machine, positive electricity is accumulated on the inner, and negative electricity on the outer coating. The reverse is the case if the jar is held by the knob, and the

external coating presented to the machine. The theory of the jar is identical with that of the condenser, and all that has been said of this applies to the jar, substituting the two armatures for the two plates, A and B, of the condenser.

To charge the jar it is held in the hand as represented in fig. 335, and the knob is applied to an electrical machine, which is at work. The positive electricity of the machine acting inductively through the sides of the glass on the tinfoil and on the hand, condenses a large quantity of electricity.

Like the condenser, the Leyden jar may be discharged either

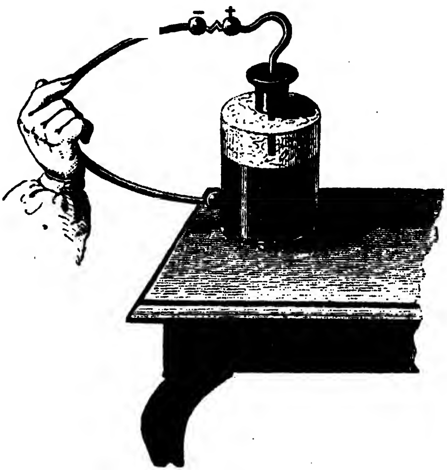

Fig. 336.

slowly or instantaneously. For the latter it is held in the hand by the outside coating (fig. 336), and the two coatings are then connected by means of the simple discharger. Care must be taken to touch *first* the external coating with the discharger, otherwise a smart shock will be felt. To discharge it slowly the jar is placed on an insulated plate, and first the internal and then the external coating touched, either with the hand or with a metallic conductor. A slight spark is seen at each discharge.

Fig. 337 represents a very pretty experiment for illustrating the slow discharge. The rod terminates in a small bell, *d*, and the

outside coating is connected with an upright metallic support, on which is a similar bell, *e*. Between the two bells a light copper ball is suspended by a silk thread. The jar is then charged in the usual manner and placed on the support, *m*. The internal armature contains a quantity of free electricity; the pendulum is attracted and immediately repelled, striking against the second bell, to which it imparts its free electricity. Being now neutralised it is again attracted by the first bell, and so on for some time, especially if the air be dry, and the jar pretty large.

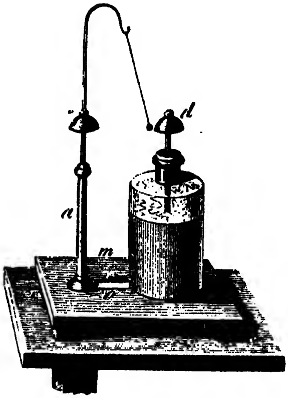

Fig. 337.

416. **Electric batteries.**—The charge which a Leyden jar can take depends on the extent of the coated surface, and for small thicknesses is inversely proportional to the thickness of the insulator. Hence the larger and thinner the jar the more powerful the charge. But very large jars are ex-

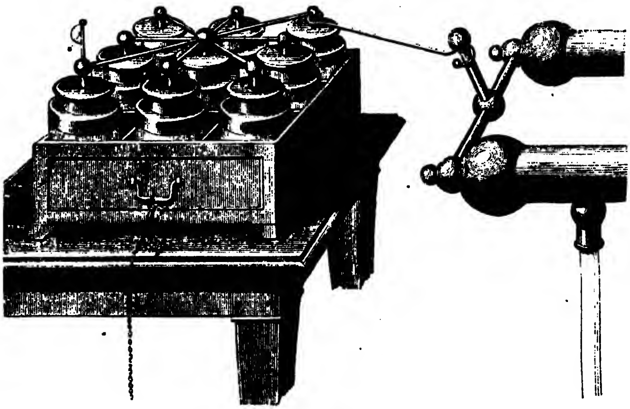

Fig. 338.

pensive, and liable to break; and, when too thin, the accumulated electricities are apt to discharge themselves through the glass, es-

pecially if it is not quite homogeneous. Leyden jars have usually from $\frac{1}{2}$ to 3 square feet of coated surface. For more powerful charges electric batteries are used.

An *electric battery* consists of a series of Leyden jars, whose internal and external coatings are respectively connected with each other (fig. 338). They are usually placed in a wooden box lined on the bottom with tinfoil. This lining is connected with two metallic handles in the sides of the box. The internal coatings are connected with each other by metallic rods, and the battery is charged by placing the internal coatings in connection with the prime conductor, while the external coatings are connected with the ground by means of a chain fixed to the handles. A quadrant electrometer fixed to the jar serves to indicate the charge of the battery. Although there is a large quantity of electricity accumulated in the apparatus the divergence is not great, for it is simply due to the free electricity on the internal coating. The number of jars is usually four, six, or nine. The larger and more numerous they are, the longer is the time required to charge the battery, but the effects are so much the more powerful.

When a battery is to be discharged, the coatings are connected by means of the discharging rod, the outside coating being touched first. Great care is required, for with large batteries serious accidents may be produced, resulting even in death.

417. **Condensing electroscope.**—We shall conclude the study of condensers by an application which Volta made of this principle to the ordinary gold leaf electroscope, by which a far greater degree of delicacy is attained (fig. 339). The rod to which the gold leaves are affixed, terminates in a disc instead of in a knob, and there is another disc of the same size provided with an insulating glass handle. The discs are covered with a layer of insulating shellac varnish (fig. 339).

To render very small quantities of electricity perceptible by this apparatus, one of the plates, which thus becomes the *collecting plate*, is touched with the body under examination. The other plate, the *condensing plate*, is connected with the ground, by touching it with the finger. The electricity of the body, being diffused over the collecting plate, acts inductively through the varnish on the neutral fluid of the other plate, attracting the opposite electricity, but repelling that of like kind. The two electricities thus become accumulated on the two plates just as in Epinus's condenser, but there is no divergence of the leaves, for the

opposite electricities counteract each other. The finger is now removed, and then the source of electricity, and still there is no

Fig. 339.

Fig. 340.

divergence; but if the upper plate be raised (fig. 340), the neutralisation ceases, and the electricity being free to move diffuses itself over the rod and the leaves, which then diverge widely. The delicacy of the apparatus is increased by adapting to the foot of the apparatus two metallic rods, terminating in knobs, for these knobs being excited by induction from the gold leaves react upon them.

CHAPTER V.

VARIOUS EFFECTS OF ACCUMULATED ELECTRICITY.

418. **Effects of the electric discharge.**—The recombination of the two electricities which constitutes the electrical discharge may be either continuous or sudden; *continuous*, or of the nature of a current, as when the two conductors of a cylinder machine are

joined by a chain or a wire; and *sudden*, as when the opposite electricities accumulate on the surface of two adjacent conductors, till their mutual attraction is strong enough to overcome the intervening resistances, whatever they may be. But the difference between a sudden and a continuous discharge is one of degree and not of kind, for there is no such thing as an absolute non-conductor, and the very best conductors, the metals, offer an appreciable resistance to the passage of electricity. Still, the difference at the two extremes of the scale is sufficiently great to give rise to a wide range of phenomena.

The phenomena of the discharge are usually divided into the *physiological*, *luminous*, *mechanical*, *magnetical*, and *chemical* effects.

Fig. 341.

419. **Physiological effects.**—The physiological effects are those produced on living beings, or on those recently deprived of life. In the first case they consist of a violent excitement which the electric

fluid exerts on, the sensibility and contractibility of the organic tissues through which it passes; and in the latter, of violent muscular convulsions which resemble a return to life.

The shock from the electrical machine has been already noticed (403). The shock taken from a charged Leyden jar, by grasping the external coating with one hand and touching the inner with the other, is much more violent, and has a peculiar character. With a small jar the shock is felt in the elbow; with a jar of about a quart capacity it is felt across the chest, and with jars of still larger dimensions in the stomach.

A shock may be given to a large number of persons simultaneously by means of the Leyden jar. For this purpose they must form a chain by joining hands. If then the first touches the outside coating of a charged jar, while the last at the same time touches the knob, all receive a simultaneous shock, the intensity of which depends on the charge, and on the number of persons receiving it. Those in the centre of the chain are found to receive a less violent shock than those near the extremities. The Abbè Nolled discharged a Leyden jar through an entire regiment of 1,500 men, all of whom received a violent shock in the arms and shoulders.

With large Leyden jars and batteries the shock is sometimes very dangerous. Priestley killed rats with batteries of 7 feet coated surface, and cats with a battery of about 4½ square yards coating.

420. **Luminous effects. Luminous jar.**—The luminous effects of electricity are in all cases due to the combination of the two fluids, positive and negative. Some of these effects have already been made known in describing *the electrical egg* and *the magic pane*. We here give a description of another one.

The *luminous jar* (fig. 342) is a Leyden jar, whose outer coating consists of a layer of varnish strewed over with metallic powder. A strip of tin fitted on the bottom is connected with the ground by means of a chain; a second band at the upper part of the coating has a projecting part, and the rod of the bottle is curved so that the knob is about ¾ of an inch distant from the projection. This bottle is suspended from the machine, and as rapidly as this is worked, large and brilliant sparks pass between the knob and the outer coating, illuminating the outside of the apparatus.

421. **Calorific effects.**—Besides being luminous, the electric spark is a source of intense heat. When it passes through inflammable

liquids, as ether or alcohol, it inflames them. An arrangement for effecting this is represented in fig. 343. It is a small glass cup through the bottom of which passes a metal rod, terminating in a knob and fixed to a metal foot. A quantity of liquid sufficient to cover the knob is placed in the vessel. The outer coating of the jar having been connected with the foot by means of a chain, the spark which passes when the two knobs are brought near each

Fig. 342.

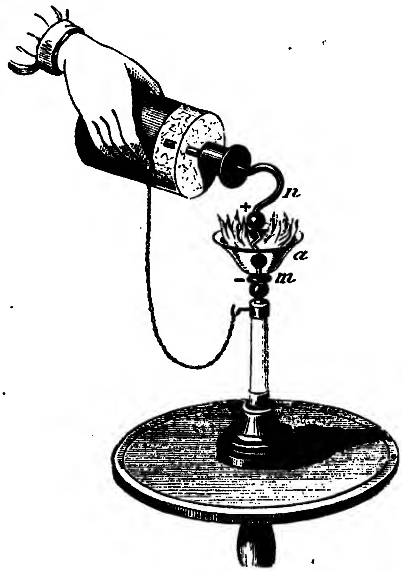

Fig. 343.

other, inflames the liquid. With ether the experiment succeeds very well, but alcohol requires to be first warmed.

Coal gas may also be ignited by means of the electric spark. A person standing on an insulated stool places one hand on the conductor of a machine which is then worked, while he presents the other to the jet of gas issuing from a metallic burner. The spark which passes ignites the gas. This experiment may be curiously varied by igniting the gas by means of a piece of ice held in the hand.

When a battery is discharged through a metal wire it becomes incandescent, and may be melted or even volatilised provided the charge be sufficiently powerful.

For this experiment an apparatus is used which is called the *universal discharger*; for it may be employed in a host of experiments on the electrical discharge. It consists (fig. 344) of two brass rods, A and B, each insulated on a glass stem. These rods can slide along hinged joints, so that they can be placed at any distance from each other and inclined in any direction. Between

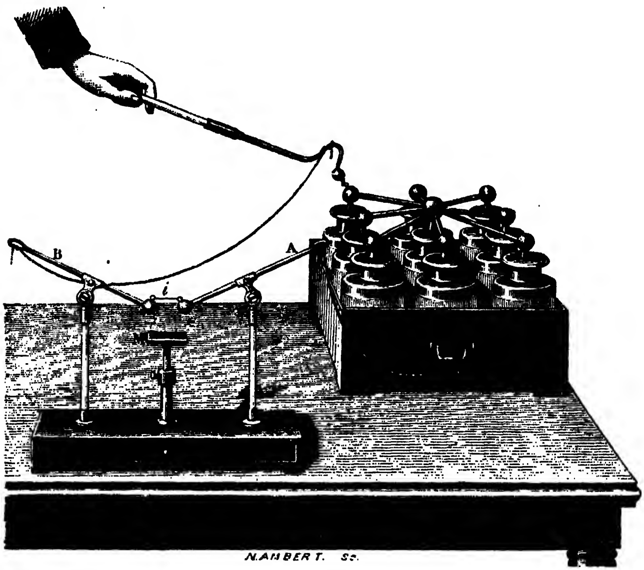

Fig. 344.

them is a small table support, which can be placed at any height, and which is intended to support objects which are to be submitted to the action of the discharge.

To melt a metal wire it is fixed at *i* to two knobs fastened on the rods, then connecting one of these by means of a chain with the outside of a powerful battery, the other is brought in contact with the inner coating, either by means of the discharging rod, or by a chain attached to a metal rod fixed on a glass handle. The moment the spark passes between the knob and the battery, the

wire of it is fine enough, is melted in incandescent globules, and is even volatilised, that is, converted into vapours which disappear in the atmosphere. If the wire is thicker it simply becomes red hot but does not melt, and if still larger it is merely heated without becoming luminous.

When an electric discharge is sent through gunpowder placed on the table of a Henley's discharger, it is not ignited, but is projected in all directions. But if a wet string be interposed in the circuit, a spark passes which ignites the powder. This arises from the retardation which electricity experiences in traversing a semi-conductor, such as a wet string; for the heating effect is proportional to the duration of the discharge.

422. **Electrical portraits.**—The fusion of metals by the electrical discharge is applied to make what are called *electrical portraits.*

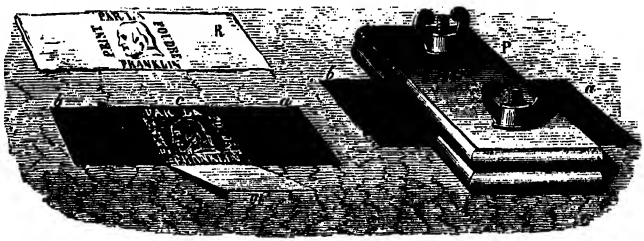

Fig. 345.

For this purpose a thin card is taken of the shape *abm*, and the design to be copied is cut out; a sheet of tinfoil is fastened on the rest of the card at *a* and *b*, but not at *c*. A leaf of gold is then placed upon the design, care being taken that it touches both the pieces of tinfoil, *a* and *b*. The lateral portion of the card, *m*, is then bent over, the card placed on a silk ribbon, and the whole pressed in a frame, P. When the discharge is passed from *a* to *b*, the tinfoil being thicker is not melted; but the gold which is very thin is volatilised, and forms on the ribbon through the pattern a brown coating, which reproduces all the details as seen in R.

423. **Mechanical effects.**—The mechanical effects are the violent lacerations, fractures, and sudden expansions which ensue when a powerful discharge is passed through a badly conducting substance. Glass is perforated, wood and stones are fractured, and gases and liquids are violently disturbed. The mechanical effects of elec-

tricity may be demonstrated by a variety of experiments. The body to be submitted to experiment is placed on the plate, N, in contact with the two knobs which terminate the rods, A and B, so that they cannot receive the discharge without transmitting it to the object on the table. Thus, for instance, if a piece of wood is placed so as to be struck in the direction of the fibres, it is smashed into pieces the moment the discharge passes.

Fig. 336 represents an arrangement for perforating a piece of glass or card. It consists of two glass columns, with a horizontal cross piece, in which is a pointed conductor, B. The piece of

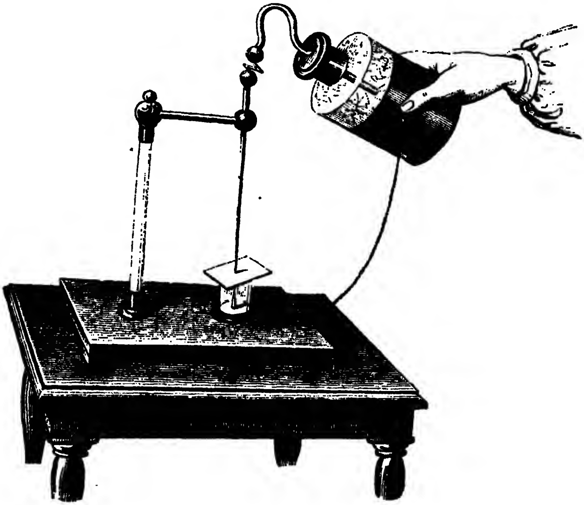

Fig. 346.

glass, A, is placed on an insulating glass support, in which is placed a second conductor, terminating also in a point, which is connected with the outside of the battery, while the knob of the inner coating is brought near the knob of B. When the discharge passes between the two conductors the glass is perforated. The experiment only succeeds with a single jar when the glass is very thin ; otherwise a battery must be used.

424. **Chemical effects.**—The chemical effects are the decompositions and recombinations effected by the passage of the elec-

trical discharge. When two gases which act on each other are mixed in the proportions in which they combine, a single spark is generally necessary to determine their combination ; but, where either of them is in great excess, a succession of sparks is necessary. Priestley found, that when a series of electric sparks was passed through moist air, its volume diminished, and blue litmus introduced into the vessel was reddened. This, Cavendish found, was due to the formation of nitric acid.

Among the chemical effects must be enumerated the formation of *ozone*, which is recognised by its peculiar odour and by certain chemical properties. The odour is perceived when electricity issues through a series of points from a conductor into the air. Its true nature is not accurately known: some regard it, and with great probability, as an allotropic modification of oxygen, and others as a teroxide of hydrogen.

425. **Magnetic effects.**—By the discharge of a large Leyden jar or battery, a steel wire may be magnetised if it is laid at right angles to the conducting wire, through which the discharge is passed, either in contact with the wire or at some slight distance. And even with less powerful discharges a steel bar or needle may be magnetised by placing it in a tube on which is coiled a fine insulated copper wire. On passing the discharge through this wire the steel becomes magnetised.

CHAPTER VI.

ATMOSPHERIC ELECTRICITY. THUNDER AND LIGHTNING.

426. **Identity of thunder and lightning.**—The first physicists who observed the zigzag motion of the electric spark, compared it to the gleam of lightning, and its crackling to the sound of thunder. But Franklin, by the aid of powerful electrical batteries, first established a complete parallel between lightning and electricity ; and he indicated, in a memoir published in 1749, the experiments necessary to attract electricity from the clouds by means of pointed rods. The electric fluid, said he, in concluding his memoir, is attracted by points ; we know not whether lightning is endowed with the same property ; but, since electricity and lightning agree in all other respects, it is probable they will not differ in this ; and the *experiment*

should be made. The experiment was tried by Dalibard in France; and Franklin, pending the erection of a pointed rod on a spire in Philadelphia, had the happy idea of flying a kite, provided with a metallic point, which could reach the higher regions of the atmosphere. In June, 1752, during stormy weather, he flew the kite in a field near Philadelphia. The kite was flown with ordinary packthread, at the end of which Franklin attached a key, and to the key a silk cord, in order to insulate the apparatus; he then fixed the silk cord to a tree, and having presented his hand to the key, at first he obtained no spark. He was beginning to despair of success, when, rain having fallen, the cord became a good conductor, and a spark passed. Franklin, in his letters, describes his emotion on witnessing the success of the experiment as being so great that he could not refrain from tears.

Franklin, who had discovered the power of points (407), but who did not understand its explanation, imagined that the kite withdrew from the cloud its electricity; it is, in fact, a simple case of induction, and depends on the inductive action which the thunder-cloud exerts upon the kite and the cord.

427. **Atmospheric electricity.**—In order to ascertain the presence of electricity in the atmosphere, many forms of apparatus have been used. To observe the electricity in fine weather, when the tension is generally small, an electrometer may be used, as devised by Saussure for this kind of investigation. It is an electroscope similar to that already described, but the rod to which the gold leaves are fixed, is surmounted by a conductor two feet in length, and terminating either in a knob or a point. To protect the apparatus against rain, it is covered with a metallic shield, four inches in diameter. The glass case is square, instead of being round, and a divided scale on its inside face indicates the divergence of the gold leaves.

To ascertain the electricity of the atmosphere, Saussure also used a copper ball, which he projected vertically with his hand. This ball was fixed to one end of a metallic wire, the other end of which was attached to a ring, which could glide along the conductor of the electrometer. From the divergence of the gold leaves, the electrical condition of the air at the height which the ball had attained could be determined. M. Becquerel, in experiments made on Mont St. Bernard, improved Saussure's apparatus by substituting for the knob an arrow, which was projected into the atmosphere by means of a bow. A gilt silk thread, eighty-eight yards long, was

fixed with one end to the arrow, while the other was attached to the stem of an electroscope.

Sometimes also kites are used, provided with a point, and connected by means of a gilt cord with an electrometer. Captive balloons are also similarly used.

A good collector of atmospheric electricity consists of a fishing rod with an insulating handle, which projects from an upper window. At the summit is a bit of lighted amadou held in a metallic forceps, the smoke of which, being an excellent conductor, conveys the electricity of the air down a wire attached to the rod. A sponge moistened with alcohol, and set on fire, is also an excellent conductor.

428. **Ordinary electricity of the atmosphere.**—By means of the different apparatus which have been described, it has been found that the presence of electricity in the atmosphere is not confined to stormy weather, but that the atmosphere always contains free electricity, sometimes positive and sometimes negative. When the sky is cloudless, the electricity is always positive, but it varies in intensity with the height of the locality, and with the time of day. The intensity is greatest in the highest and most isolated places. No trace of positive electricity is found in houses, streets, or under trees ; in towns, positive electricity is most perceptible in large open spaces, on quays, or on bridges. In all cases, positive electricity is only found at a certain height above the ground. On flat land it only becomes perceptible at a height of five feet ; above that point it increases according to a law which is not made out, but which seems to depend on the hygrometric state of the air.

When the sky is clouded, the electricity is sometimes positive and sometimes negative. It often happens that the electricity changes its sign several times in the course of the day, owing to the passage of an electrified cloud. During storms, and when it rains or snows, the atmosphere may be positively electrified one day, and negatively the next, and the numbers of the two sets of days are virtually equal.

The electricity of the ground has been found by Peltier to be always negative, but to different extents, according to the hygrometric state and temperature of the air.

Many hypotheses have been propounded to explain the origin of the atmospheric electricity. Some have ascribed it to the friction of the air against the ground, some to the vegetation of plants, or to the evaporation of water. Some, again, have compared the earth

to a vast voltaic pile, and others to a thermo-electrical apparatus. Many of these causes may, in fact, concur in producing the phenomena.

429. **Lightning.**—This, as is well known, is the dazzling light emitted by the electric spark when it shoots from clouds charged with electricity. In the lower regions of the atmosphere the light is white, but in the higher regions, where the air is more rarefied, it takes a violet tint; as does the spark of the electrical machine in a rarefied medium (405).

The flashes of lightning are sometimes several leagues in length; they generally pass through the atmosphere in a zigzag direction: a phenomenon ascribed to the resistance offered by the air condensed by the passage of a strong discharge. The spark then diverges from a white line, and takes the direction of least resistance. In vacuo electricity passes in a straight line.

Several kinds of lightning-flashes may be distinguished: 1. The *zigzag* flashes, which move with extreme velocity in the form of a line of fire with sharp outlines, and which entirely resemble the spark of an electrical machine. 2. The flashes which, instead of being linear, like the preceding, fill the entire horizon without having any distinct shape. This kind, which is most frequent, appears to be produced in the cloud itself, and to illuminate the mass. Another kind is called *heat lightning*, because it illuminates the summer nights without the presence of any clouds above the horizon, and without producing any sound. The most probable of the many hypotheses which have been proposed to account for its origin, is that which supposes it to consist of ordinary lightning flashes, which strike across the clouds at such distances that the rolling of thunder cannot reach the ear of the observer. There are, further, the lightning flashes which appear in the form of globes of fire. These, which are sometimes visible for as much as ten seconds, descend from the clouds to the earth with such slowness that the eye can follow them. They often rebound on reaching the ground; at other times they burst and explode with a noise like that of the report of many cannon.

The duration of the light of the first three kinds does not amount to a thousandth of a second, as has been determined by Mr. Wheatstone by means of a rotating wheel, which was turned so rapidly that the spokes were invisible: on illuminating it by the lightning-flash, its duration was so short that whatever the velocity of rotation

of the wheel, it appeared quite stationary; that is, its displacement is not perceptible during the time the lightning exists.

430. **Thunder.**—The *thunder* is the violent report which succeeds lightning in stormy weather. The lightning and the thunder are always simultaneous, but an interval of several seconds is always observed between these two phenomena, which arises from the fact that sound only travels at the rate of about 1,100 feet in a second (158), while the passage of light is almost instantaneous. Hence an observer will only hear the noise of thunder five or six seconds, for instance, after the lightning, according as the distance of the thunder-cloud is five or six times 1,100 feet. The noise of thunder arises from the disturbance which the electric discharge produces in the air. Near the place where the lightning strikes, the sound is dry and of short duration. At a greater distance a series of reports are heard in rapid succession. At a still greater distance the noise, feeble at the commencement, changes into a prolonged rolling sound of varying intensity. Some attribute the noise of the rolling of thunder to the reflection of sound from the ground and from the clouds. Others have considered the lightning not as a single discharge, but as a series of discharges, each of which gives rise to a particular sound. But as these partial discharges proceed from points at different distances, and from zones of unequal density, it follows not only that they reach the ear of the observer successively, but that they bring sounds of unequal density, which occasion the duration and inequality of the rolling. The phenomenon has finally been ascribed to the zigzags of lightning themselves, assuming that the air at each salient angle is at its greatest compression, which would produce the unequal intensity of the sound.

431. **Effects of lightning.**—The lightning discharge is the electric discharge which strikes between a thunder-cloud and the ground. The latter, by the induction from the electricity of the cloud, becomes charged with contrary electricity, and when the tendency of the two electricities to combine exceeds the resistance of the air, the spark passes, which is often expressed by saying that a thunder-bolt has fallen. Lightning in general strikes from above, but *ascending lightning* is also sometimes observed; probably this is the case when the clouds being negatively the earth is positively electrified, for all experiments show that at the ordinary pressure the positive fluid passes through the atmosphere more easily than negative electricity.

From the law of electric attraction (that it is inversely as the

square of the distance), the discharge ought to fall first on the nearest and best-conducting objects, and, in fact, trees, elevated buildings, metals, are more particularly struck by the discharge. Hence it is imprudent to stand under trees in stormy weather, especially if they are good conductors, such as oaks and elms. But the danger is said not to be the same under resinous trees such as pines, for they conduct less well.

The effects of lightning are very varied, and of the same kind as those of batteries (416), but of far greater intensity. The lightning discharge kills men and animals, inflames combustible matters, melts metals, breaks bad conductors in pieces. When it penetrates the ground it melts the siliceous substance in its way, and thus produces in the direction of the discharge those remarkable vitrified tubes called *fulgurites*, some of which are as much as twelve yards in length. When it strikes bars of iron, it magnetises them, and often inverts the poles of compass needles.

After the passage of lightning, a highly peculiar odour is generally produced, like that perceived in a room in which an electrical machine is being worked. This odour was first attributed to the formation of a peculiar oxygenised compound, to which the name *ozone* has been given; this, we have seen, is considered to be a peculiar allotropic modification of oxygen.

Many persons have a very lively fear of the effects of the lightning discharge. This fear would be materially diminished if we remembered the very small number of persons who are really killed by lightning. Arago has estimated the number for France at twenty in a year; that is, one victim for two million inhabitants; which is a far less proportion than that of many other accidents which do not excite nearly so much fear.

432. **Return shock.**—This is a violent and sometimes fatal shock which men and animals experience, even when at a great distance from the place where the lightning discharge passes. This is caused by the inductive action which the thunder-cloud exerts on bodies placed within the sphere of its activity. These bodies are then, like the ground, charged with the opposite electricity to that of the cloud; but when the latter is discharged by the recombination of its electricity with that of the ground, the induction ceases, and the bodies reverting rapidly from the electrical state to the neutral state, the concussion in question is produced, the *return shock*. A gradual decomposition and reunion of the electricity

produces invisible effects; yet it appears that such disturbances of the electrical equilibrium are perceived by nervous persons.

The return shock is always less violent than the direct one; there is no instance of its having produced any inflammation, yet plenty of cases in which it has killed both men and animals; in such cases no broken limbs, wounds, or burns, are observed.

The return shock may be imitated by placing a frog near the prime conductor of a strong electrical machine in action; at each spark taken from the machine, the frog experiences a smart shock.

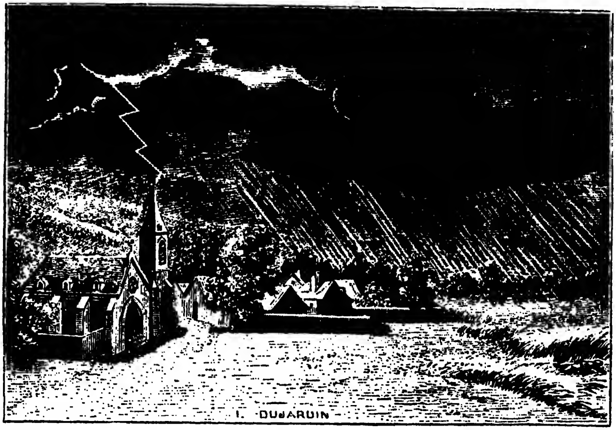

Fig. 347.

433. **Lightning conductor.**—The ordinary form of this instrument is an iron rod, through which passes the electricity of the ground attracted by the opposite electricity of the thunder-clouds. It was invented by Franklin in 1755.

There are two principal parts in a lightning conductor: the rod and the conductor. The *rod* is a pointed bar of iron, fixed vertically to the roof of the edifice to be protected; it is from six to ten feet in height, and its basal section is about two or three inches in diameter. The conductor is a bar of iron which descends from the bottom of the rod to the ground, which it penetrates to some distance. As, in consequence of their rigidity, iron bars cannot always be well adapted to the exterior of buildings, lightning conductors are best formed of wire cords, such as are used for rigging and for suspension

bridges. The conductor is usually led into a well, and to connect it better with the soil it ends in two or three branches. If there is no well in the neighbourhood, a hole is dug in the soil to a depth of six or seven yards, and the foot of the conductor having been introduced, the hole is filled with wood-ashes, which conduct very well and yet preserve the metal from oxidation. Powdered coke does equally well.

The action of a lightning conductor depending on induction and the power of points (394), Franklin, as soon as he had established the identity of lightning and electricity, assumed that lightning con-

Fig. 348.

ductors withdrew electricity from the clouds; the converse is the case. When a storm-cloud, positively electrified, for instance, rises in the atmosphere, it acts inductively on the earth, repels the positive and attracts the negative fluid, which accumulates in bodies placed on the surface of the soil the more abundantly as these bodies are at a greater height. The tension is then greatest on the highest bodies, which are therefore most exposed to the electric discharge; but if these bodies are provided with metallic points, like the rods of conductors, the negative fluid, withdrawn from the

soil by the influence of the cloud, flows into the atmosphere, and neutralises the positive fluid of the cloud. Hence, not only does a lightning conductor tend to prevent the accumulation of electricity on the surface of the earth, but it also tends to restore the clouds to their natural state, both which concur in preventing lightning discharges. The disengagement of electricity is, however, sometimes so abundant, that the lightning conductor is inadequate to discharge the ground, and the lightning strikes; but the conductor receives the discharge, in consequence of its greater conductivity, and the building is preserved.

Experiment has shown that, approximately, a lightning conductor protects a circular space around it, the radius of which is double its height. Thus a building, sixty-four yards in length, would be preserved by two rods eight yards in height, at a distance of thirty-two yards.

434. **Aurora borealis.**—The *aurora borealis*, or northern light,

Fig. 349.

or more properly *polar aurora*, is a remarkable luminous phenomenon which is frequently seen in the atmosphere at the two terrestrial poles, but more especially at the north pole. At the close of the day an indistinct light appears in the horizon in the direction of the magnetic meridian. This luminosity gradually

changes into a regular arc of a pale yellow with its concave side turned towards the earth. Finally, the rays burst all over the horizon, passing necessarily from yellow to deep green, and to the most brilliant purple. All these rays converge towards one point of the horizon, which is the prolongation of the dipping needle, and they form then a fragment of an immense luminous cupola.

When the luminous arc is formed it often remains visible for some hours; then the lustre diminishes, the colours disappear, and this brilliant phenomenon gradually diminishes, or is suddenly extinguished.

Numerous hypotheses have been devised to account for the auroræ boreales. The constant direction of their arc as regards the magnetic meridian, and their action on the magnetic needle (381), show that they ought to be attributed to electric currents in the higher regions of the atmosphere. This hypothesis is confirmed by the circumstance observed in France and other countries on August 29 and September 1, 1859, that two brilliant auroræ boreales acted powerfully on the wires of the electric telegraph; the alarums were for a long time violently rung, and despatches were frequently interrupted by the spontaneous abnormal working of the apparatus.

According to M. de la Rive the auroræ boreales are due to electric discharges which take place in polar regions between the positive electricity of the atmosphere and the negative electricity of the terrestrial globe; electricities which themselves are separated by the action of the sun, principally in the equatorial regions.

The occurrence of irregular currents of electricity, which manifest themselves by irregular disturbances of telegraphic communications, is not infrequent; such currents have received the name of *earth currents.* Sabine has found that these magnetic disturbances are due to a peculiar action of the sun, and are probably independently of its radiant heat and light. It has also been ascertained that the aurora borealis as well as earth currents invariably accompany these magnetic disturbances.

435. **St. Elmo's fire.**—This name is given by sailors to the luminous brushes or stars which sometimes appear at the tops of masts and yards of vessels, and which are sometimes accompanied by a cracking, which resembles the sparks taken from electrical machines.

These luminous effects were known to the ancients. Pliny speaks of the fiery stars seen on the ends of soldiers' lances. When they were two in number they were compared to Castor and Pollux,

and that was a favourable presage; if only one appeared, it was likened to their sister Helena, which was considered a bad omen.

St. Elmo's fire is a simple case of induction. The atmospheric electricity acting on conductors decomposes the neutral fluid, attracting the contrary electricity; which, from the power of points, being liberated at the extremities of the masts, or by the metal of the lances, gives rise to the luminous brush. The same effect is observed when, placing a metal point on the conductors of the electrical machine, it is made to work in darkness.

CHAPTER VII.

ELECTRICITY DUE TO CHEMICAL ACTION. VOLTAIC BATTERY.

436. **Galvani's experiment.**—We have already seen that the two most powerful sources of electricity are friction and chemical combination. Having described the former, we are now to be concerned with the latter. Yet we may premise that this is not a new kind of electricity, but only a new mode of production far more abundant than friction, and leading to the most remarkable effects.

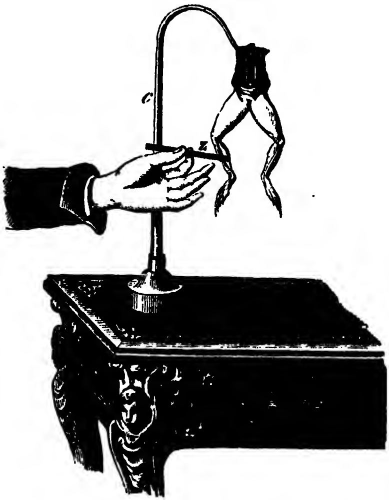

Fig. 350.

To Galvani, professor of anatomy in Bologna, is due the discovery in 1790 of these new electrical phenomena, to which he was led by a casual observation. It is said that a dead frog was accidentally suspended by a hook of copper to the iron railings of a balcony; it was observed to be violently contracted whenever the legs of the animal came in contact with the iron bars.

Galvani's observation may be reproduced in the following manner: the legs of a recently killed frog are prepared, and suspended to a copper hook, which passes between the vertebral column, and the nerve filaments on each side of it. If then the copper support and the legs are momentarily connected by a plate of zinc, at each contact a smart contraction of the muscles ensues (fig. 350).

Galvani had some time before observed that the electricity of machines produced in dead frogs analogous contractions, and he attributed the phenomena first described to an electricity inherent in the animal. He assumed that this electricity, which he called *vital fluid*, passed from the nerves to the muscles by the metallic arc, and was thus the cause of contraction. This theory met with great support, especially among physiologists, but it was not without opponents. The most considerable of these was Alexander Volta, professor of physics in Pavia.

437. **Volta's fundamental experiment.**—Galvani's attention had been exclusively devoted to the nerves and muscles of the frog; Volta's was directed upon the connecting metal. Resting on the observation, which Galvani had also made, that the contraction is more energetic when the connecting arc is composed of two metals than when there is only one, Volta attributed to the metals the active part in the phenomenon of contraction. He assumed that the disengagement of electricity was due to their contact, and that the animal parts only officiated as conductors, and at the same time as a very sensitive electroscope.

By means of the then recently invented electroscope, Volta devised several modes of showing the disengagement of electricity on the contact of metals, of which the following is the easiest to perform:

The moistened finger being placed on the upper plate of a condensing electroscope (fig. 339, p. 436), the lower plate is touched with a plate of copper, *c*, soldered to a plate of zinc, *z*, which is held in the other hand. On breaking the connection and lifting the upper plate (fig. 340), the gold leaves diverge, and, as may be proved, with negative electricity. Hence, when soldered together, the copper is charged with negative electricity, and the zinc with positive electricity. The electricity could not be due either to friction or pressure; for if the condenser plate, which is of copper, is touched with the zinc plate, *z*, the copper plate to which it is soldered being held in the hand, no trace of electricity is observed.

A memorable controvery arose between Galvani and Volta. The latter was led to give greater extension to his contact theory, and propounded the principle, that when *two heterogeneous substances are placed in contact, one of them always assumes the positive and the other the negative electrical condition.* In this form Volta's theory obtained the assent of the principal philosophers of his time.

438. **Voltaic pile.**—Reasoning from his theory of contact, Volta was led, in 1800, to the invention of the marvellous instrument which immortalised him, and which is known to this day as the *Voltaic*

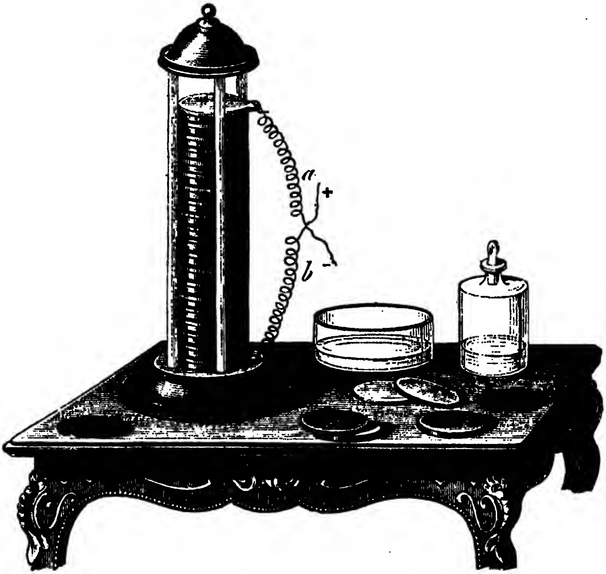

Fig. 351.

pile. Wishing to multiply the points of contact, and to collect the electricities produced by each, Volta arranged, as represented in figure 351, a disc of zinc, a disc of copper, then a round piece of cloth moistened with acidulated water, then again a disc of zinc, a disc of copper, a piece of cloth, and so forth, great care being taken always to preserve the same order. What was to be expected from such a combination? Arago says, 'I do not hesitate to assert, that

this mass so inert in appearance, this pile of so many couples of metal separated by a little liquid, is, as regards the singularity of its effects, the most remarkable instrument which has ever been invented, without even excepting the telescope and the steam engine.'

On Volta's view the union of one zinc and one copper forms *a couple*; in the above figure twenty couples are superposed, separated from each other by pieces of cloth, and all arranged in the same order, so that one extremity terminates in a disc of copper, and the other in a disc of zinc. Since its invention it has been greatly modified; but the general name of pile has been retained for all apparatus of the same kind, and the electricity furnished by piles is spoken of as *voltaic electricity*.

439. **Disengagement of electricity in chemical actions.**—The contact theory which Volta had propounded, and in which he explained the action of the pile, soon encountered objectors. Fabroni, a countryman of Volta, having observed that in the pile the discs of zinc became oxidised in contact with the acidulated water, thought that this oxidation was the principal cause of the disengagement of electricity. In England Wollaston soon advanced the same opinion, and Davy supported it by many ingenious experiments.

It is true that in the fundamental experiment of the contact theory (436) Volta obtained signs of electricity. But M. de la Rive has shown, that if the zinc be held in a wooden clamp, all signs of electricity disappear, and that the same is the case if the zinc be placed in gases, such as hydrogen or nitrogen, which exert upon it no chemical action. De la Rive has accordingly concluded, that in Volta's original experiment the disengagement of electricity is due to the chemical actions which result from the perspiration and from the oxygen of the atmosphere.

By a variety of analogous experiments it may be shown, that all chemical actions are accompanied by a disturbance of the electrical equilibrium. This is the case whether the substances concerned in the action are in the solid, liquid, or gaseous state, though of all chemical actions those between metals and liquids are the most productive of electricity. All the various resultant effects may be explained on the general principle, that when a liquid acts chemically on a metal the liquid assumes the positive electrical, and the metal the negative electrical condition.

Hence we arrive at a theory of the origin of E in the voltaic pile

which will be best illustrated by reference to the following simple experiment.

440. **Current electricity.**—When a plate of zinc and a plate of copper are partially immersed in dilute sulphuric acid, by means of delicate electroscopic arrangements it may be shown, that the zinc plate possesses a feeble charge of negative and the copper plate a feeble charge of positive electricity. At the same time there is a slight disengagement of hydrogen gas from the surface of the zinc. If now the plates be placed in direct contact, or, more conveniently, be connected by means of a metallic wire, the chemical action increases, but the hydrogen is now disengaged from the surface of the copper (fig. 352); and if the connecting wire be examined it will be found to possess the remarkable properties characteristic of the discharge of opposite electricities. So long as the metals remain in the liquid, the opposite electrical conditions of the two plates discharge themselves by means of the wire, but are instantaneously restored, and as rapidly discharged; and as these successive charges and discharges take place at such infinitely small intervals of time that they may be considered continuous, the wire is said to be traversed by an electric or voltaic *current.* The direction of this current *in the connecting wire* is assumed to be from the copper to the zinc; or, in other words, this is the direction in which the positive electricity is supposed to flow, the direction of the negative current in the wire being from the zinc to the copper. But the existence of this current is purely hypothetical, and must not be taken as more than a convenient mode of explaining the phenomena developed in the wire.

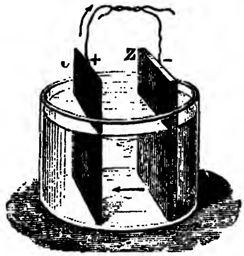

Fig. 352.

441. **Voltaic couple. Electromotive series.**—The arrangement just described, consisting of two metals in metallic contact, and a conducting liquid in which they are placed, constitutes a *simple voltaic element or couple.* So long as the metals are not in contact, the couple is said to be *open,* and when connected it is *closed.*

For the production of a voltaic current it is not necessary that one of the metals be unaffected by the liquid, but merely that the chemical action upon the one be greater than upon the other. The

metal which is most attacked is called the *positive* or *generating* plate, and that which is least attacked the *negative* or *collecting* plate. The positive metal determines the direction of the current, which proceeds *in* the liquid from the positive to the negative plate, and *out* of the liquid through the connecting wire from the negative to the positive plate.

In speaking of the direction of the current the positive current is always understood; to avoid confusion, the existence of the current in the opposite direction, the negative current, is tacitly ignored.

As a voltaic current is produced whenever two metals are placed in metallic contact in a liquid which acts more powerfully upon one than upon the other, there is great choice in the mode of producing such currents. In reference to their electrical deportment, the metals have been arranged in what is called an *electromotive series*, in which the most *electropositive* are at one end, and the most *electronegative* at the other. Hence when any two of these are placed in contact in dilute acid, the current in the connecting wire proceeds from the one lower in the list to the one higher. The prinicipal metals are as follows :—

Zinc	Nickel	Gold
Lead	Copper	Platinum
Iron	Silver	Graphite.

Thus iron placed in dilute sulphuric acid is electronegative towards zinc, but is electropositive towards copper; copper in turn is electro-negative towards iron and zinc, but is electropositive towards silver, platinum, or graphite.

The force produced by the difference in chemical action on two metals in a liquid is called the *electromotive force*; it is greater in proportion to the distance of the two metals from one another in the series. That is to say, it is greater, the greater the difference between the chemical action upon the two metals immersed. Thus the electromotive force between zinc and platinum is greater than that between zinc and iron, or between zinc and copper.

442. **Poles and electrodes.**—If the wire connecting the two terminal plates of a voltaic couple be cut, it is clear, from what has been said about the origin and direction of the current, that positive electricity will tend to accumulate at the end of the wire attached to the copper or negative plate, and negative electricity on the wire attached to the zinc or positive plate. These terminals have been called the *poles* of the battery. For experimental purposes, more especially in the decomposition of salts, plates of platinum are

attached to the ends of the wires. Instead of the term poles the word *electrode* (ἤλεκτρον and ὁδὸς, a way) is now commonly used; for these are the *ways* through which the respective electricities emerge. It is important not to confound the positive *plate* with the positive *pole* or *electrode*. The positive electrode is that connected with the negative plate, while the negative electrode is connected with the positive plate.

443. **Voltaic battery.**—When a series of voltaic elements or pairs are arranged in such a manner that the zinc of one element is connected with the copper of another; the zinc of this with the copper of another, and so on, such an arrangement is called a *voltaic battery*; and by its means the effects produced by a single element are capable of being very greatly increased.

The earliest of these arrangements was the voltaic pile devised by Volta himself.

It will be readily seen that it is merely a series of simple voltaic couples, the moistened disc acting as the liquid, and that the the terminal zinc is the negative and the terminal copper the positive pole. From the mode of its arrangement, and from its discoverer, the apparatus is known as the *voltaic pile*, a term applied to all apparatus of this kind for accumulating the effects of dynamical electricity.

The distribution of electricity in the pile varies according as it is in connection with the ground by one of its extremities, or as it is insulated by being placed on a non-conducting cake of resin or glass.

In the former case, the end in contact with the ground is neutral, and the rest of the apparatus only contains one kind of electricity; this is negative, if a copper disc is in contact with the ground, and positive if it is a zinc disc.

In the insulated pile the electricity is not uniformly distributed. By means of the proof-plane and the electroscope it may be demonstrated that the middle part is in a neutral state, and that one-half is charged with positive and the other with negative electricity, the tension increasing from the middle to the ends. The half terminated by a zinc is charged with negative electricity, and that by a copper with positive electricity. The effects of the pile will be discussed in other places.

The original form of the voltaic pile, for it possesses now only an historical interest, has a great many inconveniences; among these is the fact, that the weight of the discs of zinc and copper is so great that it presses out the acidulated liquid from the discs, and

the electrical action is soon weakened. It has received a great many improvements, the principal object of which has been to

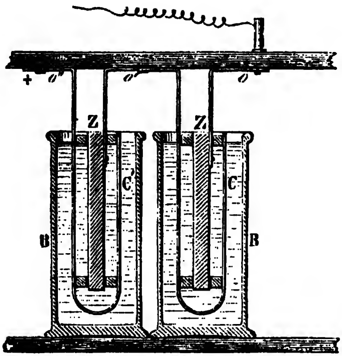

Fig. 353.

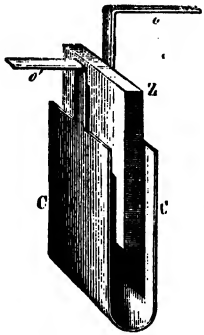

Fig. 354.

facilitate manipulation, and to produce greater electromotive force.

One of the earliest of these modifications was the crown of cups,

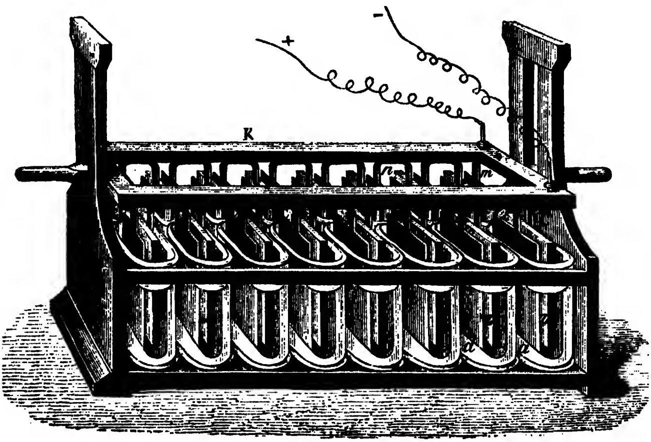

Fig. 355.

or *couronne des tasses*, invented by Volta himself: an improved form of this is known as *Wollaston's battery* (fig. 355).

Fig. 353 gives a vertical section of two consecutive Wollaston's elements. The acidulated water is contained in glass vessels, B B, in each of which is a couple. Fig. 354 represents the arrangement of one of these couples: it consists of a thick sheet of zinc and a strip of copper, *o*, by which it can be connected with the next couple. A plate of copper, C C, is bent so as to surround the plate of zinc without touching, contact being prevented by small pieces of cork. The plate, C, is provided with a copper tongue, *o′*, which is soldered to the zinc of the preceding couple and so forth.

Fig. 355 represents a pile of sixteen couples united in two parallel series of eight each. All these couples are fixed to a cross frame of wood, by which they can be raised or lowered at pleasure. When the battery is not wanted, the couples are lifted out of the liquid. The water in these vessels is usually acidulated with $\frac{1}{10}$ sulphuric and $\frac{1}{20}$ of nitric acid.

444. **Enfeeblement of the current in batteries. Secondary currents.**—The batteries already described, Volta's and Wollaston's, which consist essentially of two metals and one liquid, labour under the objection that the currents produced rapidly diminish in intensity.

This is principally due to three causes; the first is the decrease in the chemical action owing to the neutralisation of the sulphuric acid by its combination with the zinc. This is a necessary action, for upon it depends the current; it therefore occurs in all batteries, and is without remedy, except by replacement of acid and zinc. The second is due to what is called *local action*; that is, the production of small closed currents in the active metal, from the impurities it contains. These local currents rapidly wear away the active plate, without contributing anything to the general current. They are remedied by amalgamating the zinc with mercury, by which chemical action is prevented until the circuit is closed. The third arises from *secondary currents.* These are currents which are produced in the battery in a contrary direction to the principal current, and which destroy it either totally or partially. In the fundamental experiment (fig. 352), when the current is closed, sulphate of zinc is formed, which dissolves in the liquid, and at the same time a layer of hydrogen gas is gradually deposited on the surface of the copper plate. Now it has been found, that the hydrogen deposited in this manner on metallic surfaces acts far more energetically than ordinary hydrogen. In virtue of this increased activity it gradually reduces some of the sulphate of zinc formed, and a

layer of metallic zinc is formed upon the copper; hence, instead of having two different metals unequally attacked, the two metals become gradually less different, and, consequently, in the wire there are two currents tending to become equal; the total effect, and the current really observed, become weaker and weaker.

445. **Constant batteries. Daniell's.**—The serious objections to the use of what are called single fluid elements has led to their abandonment, and they are now replaced by two fluid elements, which are both more constant and more powerful. They have been replaced by batteries with two liquids, which are called *constant batteries*, because their action is without material alteration for a considerable period of time. The essential point to be attended to in securing a constant current is to prevent the polarisation of the inactive metal; in other words, to hinder any permanent deposition of hydrogen on its surface. This is effected by placing the inactive metal in a liquid upon which the deposited hydrogen can act chemically.

446. **Daniell's battery.**—This was the first form of the constant battery, and was invented by Daniell in the year 1836. As regards the constancy of its action, it is still the best of all constant batteries. Fig. 356 represents a single element. A glass or porcelain vessel, V, contains a saturated solution of sulphate of copper, in which is immersed a copper cylinder, C, open at both ends, and perforated by holes. At the upper part of this cylinder there is an annular shelf, G, also perforated by small holes, and below the level of the solution: this is intended to support crystals of sulphate of copper to replace that decomposed as the electrical action proceeds. Inside the cylinder is a thin porous vessel, P, of unglazed earthenware. This contains either a solution of common salt or dilute sulphuric acid, in which is placed the cylinder of amalgamated zinc, Z. Two thin strips of copper, *p* and *n*, fixed by binding screws to the copper and to the zinc, serve for connecting the elements in series.

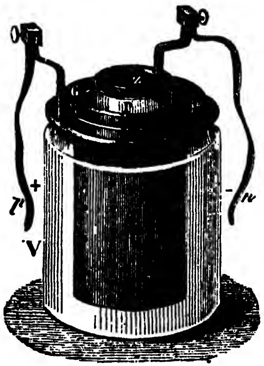

Fig. 356.

When a Daniell's element is closed, the hydrogen resulting from

the action of the dilute acid on the zinc is liberated on the surface of the copper plate, but meets there the sulphate of copper, which is reduced, forming sulphuric acid and metallic copper, which is deposited on the surface of the copper plate. In this way the sulphate of copper in the solution is taken up, and if it were all consumed, hydrogen would be deposited on the copper, and the current would lose its constancy. This is prevented by the crystals of sulphate of copper which keep the solution saturated. The sulphuric acid produced by the decomposition of the sulphate permeates the porous cylinder, and tends to replace the acid used up by its action on the zinc; and as the quantity of sulphuric acid formed in the solution of sulphate of copper is regular, and proportional to the acid used in dissolving the zinc, the action of this acid on the zinc is regular also, and thus a constant current is produced.

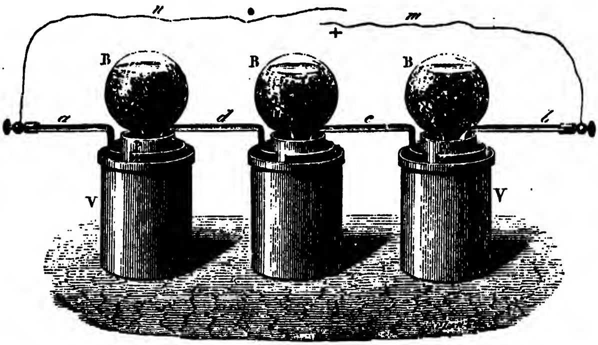

Fig. 357.

Fig. 357 represents a series of three Daniell's elements of a somewhat different pattern. Here the zinc of one is connected with the copper of the next by a copper strip. Instead of placing the crystals of sulphate of copper on a shelf in the copper plate, they are contained in glass flasks, the necks of which are immersed in a solution of sulphate of copper. This form of element is extensively used in the French telegraphs.

447. **Bunsen's battery.**—*Bunsen's battery*, also known as the *zinc carbon* battery, was invented in 1843; it is nothing more than Daniell's battery, in which nitric acid is substituted for solution of sulphate of copper, and in which copper is replaced by a cylinder

of carbon. This is made either of the graphitoidal carbon deposited in gas retorts, or by calcining in an iron mould an intimate mixture of coke and bituminous coal, finely powdered and strongly

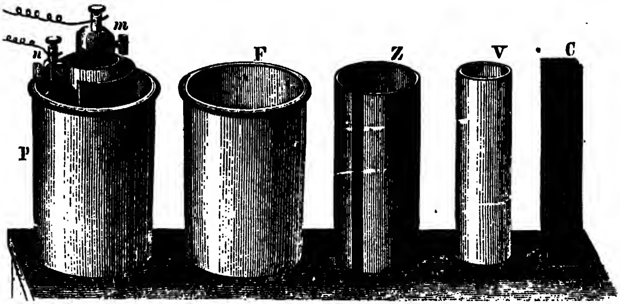

Fig. 358.

compressed. Both these modifications of carbon are good conductors. Each element consists of the following parts: 1. a vessel, F (fig. 358), either of stoneware or of glass, containing, as in Daniell's, dilute sulphuric acid; 2. a hollow cylinder, Z, of amalgamated zinc; 3. a porous vessel, V, in which is ordinary nitric acid; 4. a cylinder of carbon, C, prepared in the above manner. In the

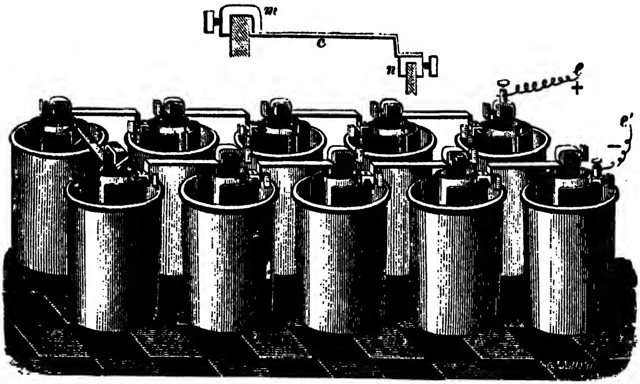

Fig. 359.

vessel, F, the zinc is first placed, and in it the carbon as seen in P. To the carbon is fixed a binding screw, *m*, (fig. 359), to which a copper wire is attached; forming the positive pole. The zinc is provided with a similar binding screw, *n*, and wire, which is thus the negative pole.

In Bunsen's battery the hydrogen resulting from the action is liberated on the surface of the carbon. This being surrounded by nitric acid, the hydrogen decomposes this acid, forming water and *hyponitrous acid*, which dissolves, or is subsequently disengaged as nitrous fumes. And, though the hydrogen is most completely got rid of by the decomposition of the nitric acid, the production of these nitrous fumes is very noxious.

The elements are arranged to form a battery (fig. 359) by connecting each carbon to the zinc of the following one by means of the clamps, *mn*, and a strip of copper, *c*, represented in the top of the figure. The copper is pressed at one end between the carbon and the clamp, and at the other it is soldered to the clamp, *n*, which is fitted on the zinc of the following element, and so forth. The clamp of the first carbon and that of the last zinc are alone provided with binding screws, to which are attached the wires.

CHAPTER VIII.

EFFECTS OF THE BATTERY.

448. **Physiological effects.**—The remarkable phenomena of the voltaic battery may be classed under the heads physiological, chemical, mechanical, and physical effects; and these latter may be again subdivided into the thermal, luminous, and magnetic effects. All are due to the recombination of the opposite electricities like those of the electrical machine; but they are far more remarkable and more energetic, owing to the continuity of their action. To produce them the body experimented upon must be connected on the one side with the positive and on the other with the negative pole.

The *physiological effects* consist of shocks and violent contractions which the current produces in the muscles, not only of living, but of dead animals, as has been seen in Galvani's experiment with the frog.

When the electrodes of a strong battery are held in the two hands a violent shock is felt, resembling that of a Leyden jar, especially if the hands are moistened with acidulated or saline water, which increases the conductivity. The shock is more violent in proportion to the number of elements used; with a Bunsen's battery of 50 to 60 couples the shock is very strong, with 150 or 200 couples it is unbearable, and even dangerous when continued. It is less perceptible in the fore part of the arms than the shock of the Leyden jar, and, when transmitted through a chain of several persons, it is generally only felt by those nearest the poles.

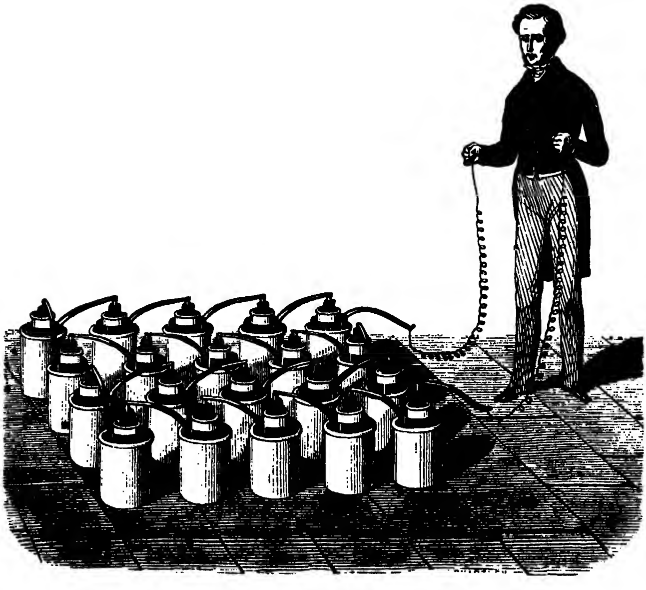

Fig. 360.

The shock, as in the case of the Leyden jar, is due to the recomposition of the two electricities ; with this difference, that with the Leyden jar the discharge being instantaneous, the resultant shock is so also ; while in the latter case, as the battery is immediately recharged after each discharge, the shocks succeed each other with rapidity.

John Aldini, a nephew of Galvani, was the first to study the

action of the battery on dead animals. He came to Paris at the beginning of the present century, and repeated on a large scale several of his experiments at the veterinary school of Alfort near Paris.

449. **Thermal effects.**—When a voltaic current is passed through a metallic wire the same effects are produced as by the discharge of an electric battery; the wire becomes heated and even incandescent if it is very short and thin. With a powerful battery all metals are melted, even iridium and platinum, the least fusible of metals. Carbon is the only body which hitherto has not been fused by it. M. Despretz, however, with a battery composed of 600 Bunsen's elements joined in six series, has raised rods of very pure carbon to such a temperature that they were softened and could be welded together, indicating an incipient fusion.

A battery of thirty to forty Bunsen's elements is sufficient to melt and volatilise fine wires of lead, tin, zinc, copper, gold, silver, iron, and even platinum, with differently coloured sparks. Iron and platinum burn with a brilliant white light; lead with a purple light; the light of tin and of gold is bluish white; the light of zinc is a mixture of white and gold; finally, copper and silver give a green light. The thermal effects of the voltaic current are used in firing mines for military purposes and for blasting operations.

450. **Luminous effects.**—In closing a voltaic battery a spark is obtained at the point of contact, which is frequently of great brilliance. A similar spark is also perceived on breaking contact. These luminous effects are obtained when the battery is sufficiently powerful, by bringing the two electrodes very nearly in contact; a succession of bright sparks springs sometimes across the interval, which follow each other with such rapidity as to produce a continuous light. With eight or ten of Grove's elements brilliant luminous sparks are obtained by connecting one terminal of the battery with a file, and moving its point along the teeth of another file connected with the other terminal.

The most beautiful effect of the electric light is obtained when two pencils of charcoal are connected with the terminals of a powerful battery in the manner represented in fig. 361. The two charcoals being placed in contact the current passes, and their ends soon become incandescent. If they are then removed to a distance of about the tenth of an inch, according to the intensity of the current, a luminous arc extends between the two points, which has an exceedingly brilliant lustre, and is called the *voltaic arc.*

The length of this arc varies with the force of the current. In air it may exceed two inches with a battery of 600 elements. If the charcoal attached to the positive pole be examined, it will be found to have become hollowed, and worn away, while the negative charcoal has increased. It thus seems that the carbon is transported from the positive to the negative pole, and that this is the

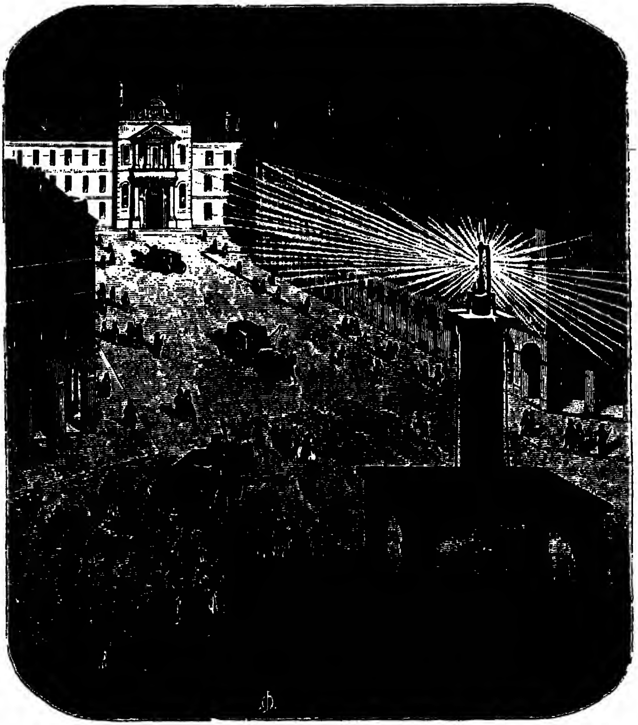

Fig. 361.

manner in which the transmission of the electricity between the two poles is effected.

The intensity of the electric light is very great. Bunsen, in experimenting with forty-eight couples, and removing the charcoals

to a distance of a quarter of an inch, found that the intensity of the electric light is equal to that of 572 candles.

Too great precautions cannot be taken against the effects of the electric light when they attain a certain intensity. The light of 100 couples, he says, may produce very painful affections of the eyes. With 600, a single moment's exposure to the light is sufficient to produce very violent headaches and pains in the eye, and the whole frame is affected as by a powerful sunstroke.

Attempts have been made to apply the electric light to the illumination of rooms and even of streets; but partly the cost and partly the difficulty of producing with it a uniform illumination, inasmuch as the shadows are thrown into too sharp relief, have hitherto been great obstacles to its use. Yet it is advantageously applied in special cases, such as the photo-electric microscope, illuminations in theatres, &c. Fig. 361 represents an arrangement for public illumination. On a convenient support, an electric lamp is placed; this is a mechanism which is worked by the current from a powerful battery, and which keeps the carbon poles at a suitable distance, a condition necessary for the permanence and steadiness of the light.

DECOMPOSITION OF WATER.

451. **Chemical effects.**—These are among the most important of all the actions, either of the simple or compound circuit. They

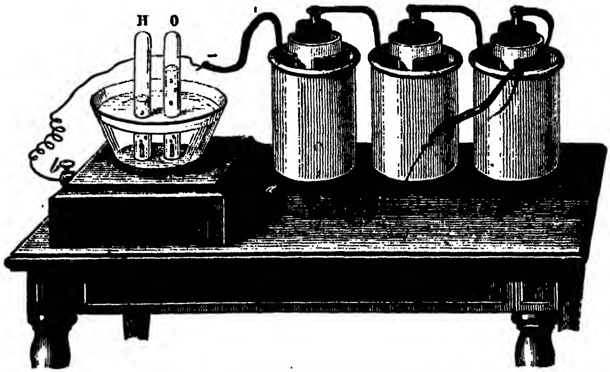

Fig. 362.

consist of the separation and transport of the elements of the

bodies traversed by the current. The first decomposition effected by the battery was that of water, obtained in 1800 by Carlisle and Nicholson by means of a voltaic pile. Water is rapidly decomposed by four or five Bunsen's cells; the apparatus (fig. 362) is very convenient for the purpose. It consists of a glass vessel fixed on a wooden base. In the bottom of the vessel two platinum electrodes are fitted, communicating by means of copper wires with the binding screws, *a* and *b*. The vessel is filled with water to which some sulphuric acid has been added to increase its conductivity, for pure water is a very imperfect conductor; two glass tubes filled with water are inverted over the electrodes, and, on interposing the apparatus in the circuit of a battery, decomposition is rapidly set up, and gas bubbles rise from the surface of each pole. The volume of gas liberated at the negative pole is about double that at the positive, and on examination the former gas is found to be hydrogen and the latter gas oxygen. This experiment accordingly gives at once the qualitative and quantitative analysis of water; for it shows that its composition consists of two parts by volume of hydrogen to one part by volume of oxygen.

452. **Electrolysis.**—To those substances which, like water, are resolved into their elements by the voltaic current, the term *electrolyte* has been applied by Faraday, to whom the principal discoveries in this subject and the nomenclature are due; *electrolysis* is the decomposition by the voltaic battery.

By means of the battery, the compound nature of several substances which had previously been considered as elements has been determined. By means of a battery of 250 couples, Davy, shortly after the discovery of the decomposition of water, succeeded in decomposing the alkalies potass and soda, and proved that they were the oxides of the hitherto unknown metals *potassium* and *sodium*. The decomposition of potass may be demonstrated with the aid of the battery of four to six elements in the following manner: a small cavity is made in a piece of solid caustic potass, which is moistened, and a drop of mercury placed in it. The potass is placed on a piece of platinum connected with the positive pole of the battery. The mercury is then touched with the negative pole. When the current passes, the potass is decomposed, oxygen is liberated at the positive pole, while the potassium liberated at the negative pole amalgamates with the mercury. On distilling this amalgam out of contact with air, the mercury passes off, leaving the potassium.

The decomposition of binary compounds, that is, bodies containing two elements, is quite analogous to that of water and of potass; one of the elements goes to the positive, and the other to the negative pole. The bodies separated at the positive pole are called *electronegative* elements, because at the moment of separation they are considered to be charged with negative electricity, while those separated at the negative pole are called *electropositive* elements. One and the same body may be electronegative or electropositive, according to the body with which it is associated. For instance, sulphur is electronegative towards hydrogen, but is electropositive towards oxygen. The various elements may be arranged in such a series that any one in combination is electronegative to any following, but electropositive towards all preceding ones. This is called the *electrochemical series*, and begins with oxygen as the most electronegative element, terminating with potassium as the most electropositive.

APPLICATION OF THE DECOMPOSITION PRODUCED BY THE BATTERY.

453. **Electrotype.**—In the ordinary methods of reproducing in metal statues, basreliefs, etc., moulds of dry earth are prepared, which are faithful hollow copies of these objects; then either melted iron or bronze are run into these; when the metal is solid, an exact copy in relief is obtained of the object. In electrotypes, a mould of the object to be produced is required, but the reproduction is effected without either fusion or fire. The current of a battery quietly deposits on a faithful impression of the object a layer of metal of any desired thickness. This is the meaning of the term *galvanoplastics*, which is derived from the word galvanism, and from a Greek word which signifies 'to model.'

The practice of electrometallurgy consist of two distinct operations; firstly, the preparation of the mould or impression of the objects to be reproduced; and, secondly, the deposit of the metal in this mould. The first is the most delicate, and that on which mainly depends the success of the operation.

Various substances are used for taking impressions, wax, stearine, fusible metal, gutta percha, etc. Of these the most useful at any rate for small objects is gutta percha. This substance, which is hard at ordinary temperatures, softens when placed in warm water. When it has acquired the proper degree of softness, a plate of this

is placed on the object to be copied and pressed against it. When the object is of metal, a medal for instance, the gutta percha is easily detached as soon as it is cold ; but with a wood engraving, or a plaster cast, the gutta percha adheres, and cannot be detached without danger of tearing. This may be remedied by previously brushing the mould over with black lead or *graphite*, as it ought to be called.

Suppose the subject to be reproduced is a medal (fig. 364), when the mould is obtained we have this metal hollow and inverted. It is now necessary to make its surface a conductor, for gutta percha being an insulator could not transmit the current

Fig. 363.

Fig. 364.

from the battery. This is effected by brushing it over very carefully with graphite (which is a very good conductor) in all those places where the metal is to be deposited. Three copper wires are then fixed to it, one of which is merely a support, while the two others conduct the current to the metallic surface.

The mould is then ready for the metal to be deposited upon it ; copper is ordinarily used, but silver and gold also deposit well.

In order to take a copper cast, a bath is filled with saturated solution of sulphate of copper and two copper rods, B and A, stretched across (fig. 365) : one connected with the negative and

the other with the positive pole of a Grove's, or preferably, from its greater constancy, a Daniell's element. From the rod connected with the negative pole, B, is suspended the mould, *m*, and from the other A, a plate of copper, C. The current being thus closed, the sulphate of copper is decomposed, acid is liberated at the positive pole, while copper is deposited at the negative pole, on the mould suspended from the rod, B, to which indeed several moulds may be attached.

The copper plate suspended from the positive pole serves a double purpose; it not only closes the current, but it keeps the

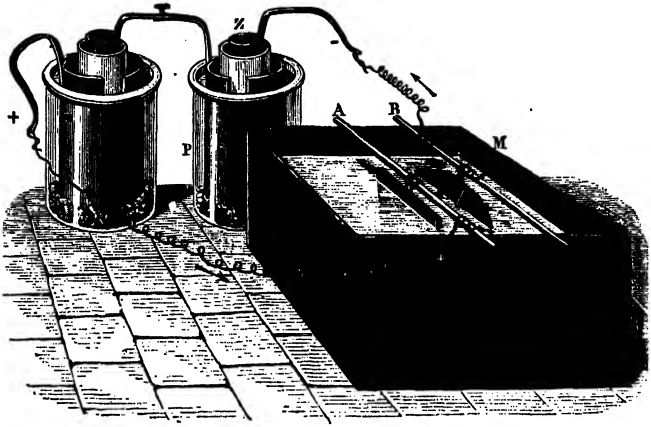

Fig. 365.

solution in a state of concentration, for the acid liberated at the positive pole dissolves the copper, and reproduces a quantity of sulphate of copper equal to that which has been decomposed. The bath always remains, therefore, at the same degree of concentration, that is to say, always contains the same amount of salt in solution, which is a condition necessary for forming a uniform deposit.

454. **Electrogilding.**—The old method of gilding was by means of mercury. It was effected by an amalgam of gold and mercury, which was applied on the metal to be gilded. The objects thus covered were heated in a furnace, the mercury volatilised, and the gold remained in a very thin layer on the objects. The same process was used for silvering; but they were expensive and un-

healthy methods, and have now been entirely replaced by electrogilding and electrosilvering. Brugnatelli, a pupil of Volta, appears to have been the first, in 1803, to observe that a body could be gilt by means of the battery and an alkaline solution of gold; but M. de la Rive was the first who really used the battery in gilding. The methods both of gilding and silvering owe their present high state of perfection principally to the improvements of Elkington, Ruolz, and other physicists.

The difference between electrogilding and electrosilvering and the processes described in the previous article is this, that, in the former, the metal is deposited on a mould in order to reproduce the objects given; while, in the latter, the objects are permanently covered with a thin layer of gold or silver.

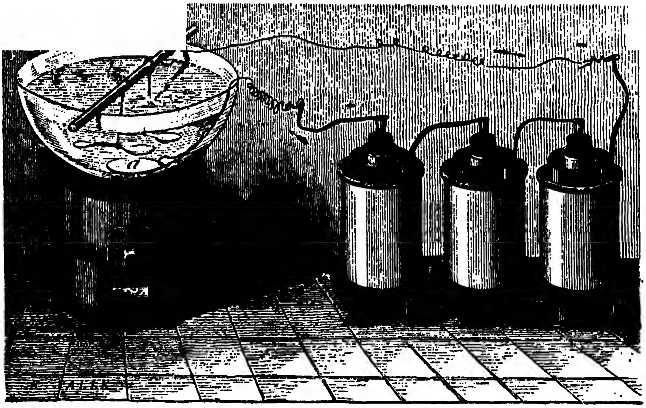

Fig. 366.

The pieces to be coated have to undergo three preparatory processes.

The first consists in heating them so as to remove the fatty matter which has adhered to them in previous processes.

As the objects to be gilt are usually of copper, and their surface during the operation of heating becomes covered with a layer of suboxide or of protoxide of copper, this is removed by the second operation. For this purpose the objects, while still hot, are immersed in very dilute nitric acid, where they remain until the

oxide is removed. They are then rubbed with a hard brush, washed in distilled water, and dried in gently heated sawdust.

To remove all spots they must undergo the third process, which consists in rapidly immersing them in ordinary nitric acid, and then in a mixture of nitric acid, bay salt, and soot. They are then well washed in distilled water, and dried as before in sawdust.

When thus prepared the objects are attached to the negative pole of a battery of three or four cells, and if they are to be silvered they must be immersed in a bath of silver kept at a temperature of sixty to eighty degrees. They remain in the bath for a time which depends on the thickness of the desired deposit. There is great difference in the composition of the baths. That most in use consists of two parts of cyanide of silver and two parts of cyanide of potassium, dissolved in 250 parts of water. In order to keep the bath in a state of concentration, a piece of silver is suspended from the positive electrode, which dissolves in proportion as the silver dissolved in the bath is deposited on the objects attached to the negative pole.

The processes of electrogilding are quite the same as those of electrosilvering, with the exception that a bath of gold is used instead of one of silver, and the positive plate terminates in a plate of gold. The bath used is a solution of cyanide of gold and potassium.

The method which has just been described can not only be used for gilding copper, but also for silver, bronze, brass, German silver, etc. But other metals, such as iron, steel, zinc, tin, and lead, are very difficult to gild well. To obtain a good coating they must first be covered with a layer of copper by means of the battery and a bath of sulphate of copper; the copper with which they are coated is then gilded, as in the previous case.

CHAPTER IX.

ELECTROMAGNETISM.

455. **Relation between magnetism and electricity.**—Early in the history of the two sciences, the analogy was remarked which existed between the phenomena of electricity and magnetism. It was observed that, in both cases, like kinds of electricity repelled each other, as also did like kinds of magnetism, and that unlike

kinds attracted. It had moreover been observed that lightning, in striking a ship, often reversed the polarity of compass needles, and even sometimes robbed them of all magnetic power. But though there were many points of resemblance between electricity and magnetism, the dissimilarities were numerous. For instance, magnetic properties cannot be transmitted to good conductors, as can electrical properties. A magnet placed in contact with the earth does not lose its magnetism as does an electrified body. Again, electricity can be produced in all bodies, while magnetism is only manifested by a very small number. Among these resemblances and dissimilarities, nothing could be affirmed respecting the identity of the causes which produce electricity and magnetism, when, towards the end of 1819, Oersted, a professor of physics in Copenhagen, made a memorable discovery, which for ever intimately connected these two physical agents. Thus arose a new branch of science called *electromagnetism*, to express that the phenomena are at once magnetic and electrical.

456. **Action of current upon magnets.**—The fact which Oersted discovered was the directive action of currents upon magnets. He found that *electrical currents have a directive action upon the magnetic needle, and always tend to set it at right angles to their own direction.*

To verify this action of currents upon magnets, the experiment is arranged as shown in fig. 367. A magnetic needle, movable upon a pivot, being at rest in the direction of the magnetic meridian, a wire traversed by a current is brought near it, care being taken to bring it lengthways. The needle is then seen to deviate from its position of rest, oscillate, and ultimately come to rest in a position which is nearly at right angles to that of the current; and the more nearly, the more powerful the current.

In this experiment the direction in which the north pole is deflected varies with the direction of the current; if it goes from south to north above the needle, the north pole is deflected to the west; if, on the contrary, it goes from north to south but still above the needle, the north pole is deflected to the east. When the current passes below the needle, the same phenomena are reproduced in exactly the reverse order. All these different cases have been reduced to a single one by Ampère.

457. **Ampère's rule.**—Ampère has given the following *memoria technica*, by which all the various directions of the needle under the influence of a current may be remembered. If we imagine an

observer placed in the connecting wire in such a manner that the current entering by his feet issues by his head, and that his face is always turned towards the needle, we shall see that, in the above four positions, the north pole is always deflected towards the left of the observer. By thus personifying the current, the different cases

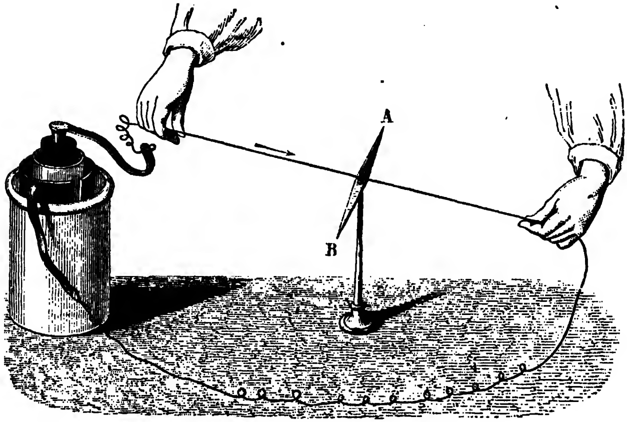

Fig. 367.

may be comprised in this general principle : *In the directive action of currents on magnets, the north pole is always deflected towards the left of the current.*

458. **Action of magnets and of the earth on currents.**—Just as currents act on magnets, so also magnets act upon currents. To prove this, a circle of copper wire provided at the ends with steel points dip in two mercury cups (fig. 368). These mercury cups are at the ends of two metal rods attached to two vertical columns, with which can be connected the poles of Bunsen's element. By this arrangement, which is known as Ampère's stand, we have a movable circuit continually traversed by a current. When this circuit is at rest, if a powerful magnet be placed beneath the circuit, but in its plane, the circuit will be seen to turn *and set transversely to the bar, which is the converse of Oersted's experiment.*

The terrestrial globe, which acts like a magnet on magnetic needles, acts in the same manner on the movable circuits, that is, it directs them perpendicularly to the magnetic meridian. This

action may be demonstrated by the above apparatus. With this view, before the current traverses the circuit, it is placed in the magnetic meridian, and then the two poles of the battery are connected with the two columns : the circuit is soon observed to set

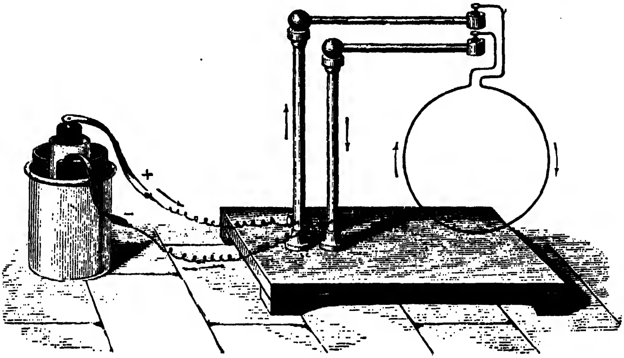

Fig. 368.

transversely to its first position, and so that, in the lower part of the circuit, the direction of the current is from east to west.

459. **Galvanometer, or multiplier.**—The name *galvanometer*, *multiplier*, or *rheometer* is given to a very delicate apparatus, by which the existence, direction, and intensity of currents may be determined. It was invented by Schweïgger in Germany a short time after Oersted's discovery.

In order to understand its principle, let us suppose a magnetic needle suspended by a filament of silk (fig. 369), and surrounded in the plane of the magnetic meridian by a copper wire forming a complete circuit round the needle in the direction of its length. When this wire is traversed by a current, it follows, from what has been said in the previous paragraph, that in every part of the circuit an observer lying in the wire in the direction of the arrows, and looking at the needle, *ab*, would have his left always turned towards the same point of the horizon, and consequently, that the action of the current in every part would tend to turn the north pole in the same direction: that is to say, that the actions of the four branches of the circuit concur to give the north pole the same direction. By coiling the copper wire in the direction of the needle, as represented in the figure, the action of the current has been *multiplied*. If

instead of a single one, there are several circuits, provided they are insulated, the action becomes still more multiplied, and the deflection of the needle increases; or, what is the same thing, a much feebler current will produce deflection.

As the directive action of the earth continually tends to keep the needle in the magnetic meridian, and thus opposes the action of the current, the effect of the latter is increased by using an astatic system of two needles as shown in fig. 370. The action of the earth on the needle is then very feeble, and, further, the actions of the current on the two needles become accumulated. In fact, the action of the circuit, from the direction of the current indicated by the arrows, tends to deflect the north pole of the lower needle towards the west. The upper needle, $a'b'$, is subjected to the action

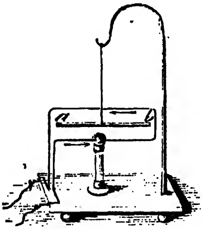

Fig. 369.

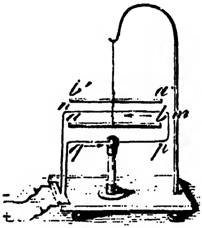

Fig. 370.

of two contrary currents, *mn* and *qp*, but as the first is nearer, its action preponderates. Now this current, passing below the needle, evidently tends to turn the pole, a', towards the east, and, consequently, the pole, b', towards the west; that is to say, in the same direction as the pole, a, of the other needle.

From these principles it will be easy to understand the theory of the *multiplier*. The apparatus, represented in fig. 371, consists of a thick brass plate resting on levelling screws; on this is a copper frame, on which is coiled a great number of turns of wire covered with silk. The two ends terminate in binding screws, *n* and *m*. Above the frame is a graduated circle, with a central slit parallel to the direction in which the wire is coiled. By means of a very fine filament of silk, an astatic system is suspended; it consists of two needles, *ab* and $a'b'$, one above the scale, and the other within the circuit itself.

In using the instrument it is so adjusted that the needles, and also the slit, are in the magnetic meridian.

459*a*. **Uses of the galvanometer.**—To show, by means of the multiplier, the electricity developed in chemical actions, for instance in the action of acids on metals, two platinum wires may be attached to the binding screws, *m* and *n*. Then one of them is plunged in very dilute sulphuric acid, and the other placed in contact with a piece of zinc held in the hand, which is dipped in the liquid. An immediate deflection is observed, which

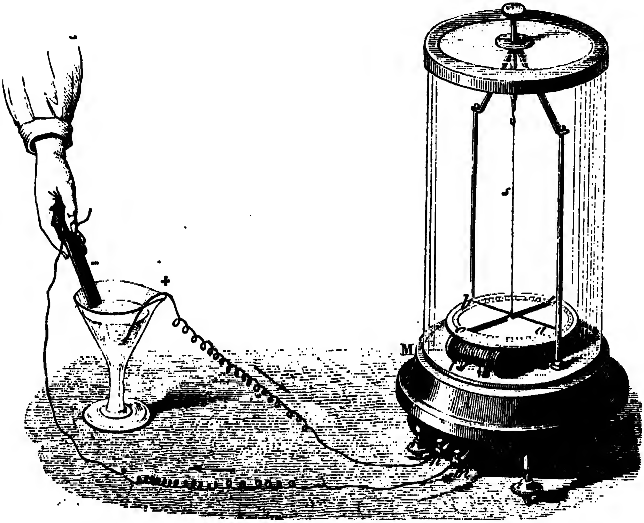

Fig. 371.

indicates the existence of a current; and from the direction which the north pole of each needle assumes, it is seen that the direction of the current is that indicated by the arrows. From which we may conclude, in accordance with the explanation given as to the origin of electricity in the simple voltaic circuit, that the acid is positively electrified and the zinc negatively.

The length and diameter of the wire vary with the purpose for which the galvanometer is intended. For one which is to be used in observing the currents due to chemical actions, a wire about $\frac{1}{6}$ millimeter in diameter, and making about 800 turns, is well

adapted. Those for thermo-electric currents, which have low intensity, require a thicker and shorter wire, for example, thirty turns of a wire $\frac{2}{3}$ millimeter in diameter. For very delicate experiments, as in physiological investigations, galvanometers with as many as 30,000 turns have been used.

460. **Magnetisation by electrical currents.**—From the influence which currents exert upon magnets, turning the north pole to the left and the south pole to the right, it is natural to think, that by acting upon magnetic substances in the natural state the currents would tend to separate the two magnetic fluids. In fact, when a wire traversed by a current is immersed in iron filings, they adhere to it in large quantities, but become detached as soon as the current ceases, while there is no action or any other non-magnetic metal.

The action of currents on magnetic substances is well seen in an experiment due to Ampère, which consists in coiling an insulated copper wire round an unmagnetised steel bar. If a current be

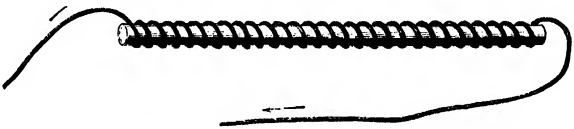

Fig. 372.

passed through the wire, even for a short time, the bar becomes strongly magnetised. The same effect is produced with a bar of soft iron, but in this case the magnetisation is temporary; when the current ceases, the iron, which is destitute of coercive force, reverts instantaneously to the natural state; and, if in this experiment, we imagine an observer floating in the direction of the current, the north pole is always on his left hand.

If the discharge of a Leyden jar be transmitted through the wire by connecting one end with the outer coating, and the other with the inner coating, the bar is also magnetised. Hence both voltaic and frictional electricity can be used for magnetising.

CHAPTER X.

ELECTRODYNAMICS.

461. **Reciprocal action of currents on currents.**—Ampère did not restrict himself to trying the action of magnets and of the earth upon movable currents; he went further, and was led to the important discovery, that electrical currents act on each other as do magnets; and he thus created an entirely new branch of physics, to which the name *electrodynamics* has been given. The actions which currents exert on each other are different according as they are parallel or angular.

I. *Two currents which are parallel, but in contrary directions, repel each other.*

II. *Two currents, parallel and in the same direction, attract each other.*

To verify these laws use is made of the apparatus represented in fig. 373. On a wooden support are fixed two brass columns, A and B, joined at the top by a wooden cross-piece. In the centre of this is a brass binding screw, *a*, and below this a mercury cup. In this is placed an iron pivot which joins the end of a copper wire. This wire is coiled in the manner represented in the figure, terminating in a mercury cup on the base of the apparatus. It thus forms a circuit movable about the pivot.

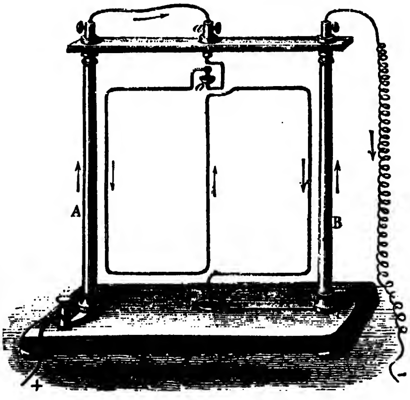

Fig. 373.

That being premised, the circuit is arranged in the plane of the two columns, as shown in fig. 373, and the current from a Bunsen's

battery is passed through it to the foot of the column, A; it passes thence by a copper wire to a binding screw, *a*; thence into the cup, *ao*, traverses the entire movable circuit in the direction of the arrows, reaches the cup, C, whence, by a copper strip, it reaches the foot of the column, B, rises in this, and ultimately returns to the battery. When the current passes, the circuit moves away from the columns, and, after a few oscillations, comes to rest crosswise to its original position; thus showing that the ascending current in the columns and the descending current in the circuit repel each other, thereby proving the first law.

The second law may be established by means of the same apparatus, replacing the movable circuit depicted in fig. 373 by another so arranged that the current is ascending both in the columns and in the two branches of the circuit. When the movable circuit is displaced, and the current is passed, the latter returns briskly towards the columns.

Law of angular currents.—In the case of two angular currents, one fixed and the other movable, Ampère found that there was attraction when both the currents moved towards, or both away from, the apex of the angle; and that repulsion took place when, one current moving towards the apex the other moved away from it.

SOLENOIDS.

462. **Structure of a solenoid.**—A solenoid is a system of equa and parallel circular currents formed of the same piece of covered copper wire, and coiled in the form of a helix or spiral, as represented in fig. 374. A solenoid, however, is only complete when part of the wire, BC, passes in the direction of the axis in the interior of the helix. With this arrangement, when the circuit is suspended in the mercury cups, *ab*, of the apparatus (fig. 373), and a current is passed through, it is directed by the earth exactly as if it were a magnetic needle. If the solenoid be removed it will, after a few oscillations, return, so that its axis is in the magnetic meridian. Further, it will be found that, in the lower half of the coils of which the solenoid consists, the direction of the current is from

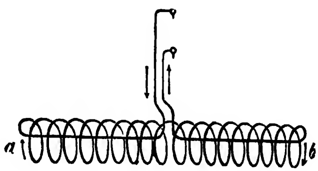

Fig. 374.

east to west; in other words, the current is *descending* on that side of the coil turned towards the east, and ascending on the west. In this experiment the solenoid is directed like a magnetic needle, and the *north pole*, as in magnets, is that end which points towards the north, and the *south pole* that which points towards the south.

463. **Mutual actions of magnets and solenoids.**—Exactly the same phenomena of attraction and repulsion exist between solenoids and magnets as between magnets. For if to a movable solenoid traversed by a current, one of the poles of a magnet be presented,

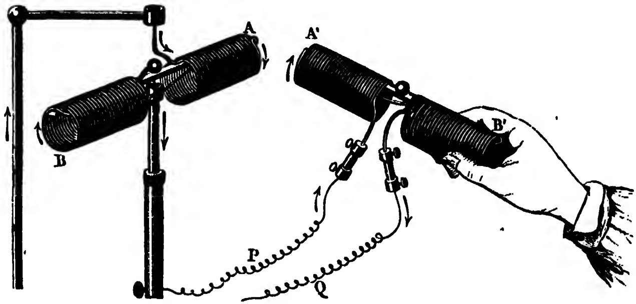

Fig. 375.

attraction or repulsion will take place, according as the poles of the magnet and of the solenoid are of contrary or of the same name. The same phenomenon takes place when a solenoid, traversed by a current and held in the hand, is presented to a movable magnetic needle. Hence the law of attractions and repulsions applies exactly to the case of the mutual action of solenoids and of magnets.

464. **Mutual actions of solenoids.**—When two solenoids traversed by a powerful current are allowed to act on each other, one of them being held in the hand, and the other being movable about a vertical axis, as shown in fig. 375, attraction and repulsion will take place, just as in the case of two magnets. These phenomena are readily explained by reference to what has been said about the mutual action of the currents, bearing in mind the direction of the currents in the extremities presented to each other.

465. **Ampère's theory of magnetism.**—Ampère has propounded a most ingenious theory, based on the analogy which exists be-

tween solenoids and magnets, by which all magnetic phenomena may be referred to electrodynamical principles.

Instead of attributing magnetic phenomena to the existence of two fluids, Ampère assumes that each individual molecule of a magnetic substance is traversed by a closed electric current. When the magnetic substance is not magnetised, these molecular currents, under the influence of their mutual attractions, occupy such positions that their total action on any external substance is null. Magnetisation consists in giving to these molecular currents a parallel direction, and the stronger the magnetising force the more perfect the parallelism. The *limit of magnetisation* is attained when the currents are completely parallel.

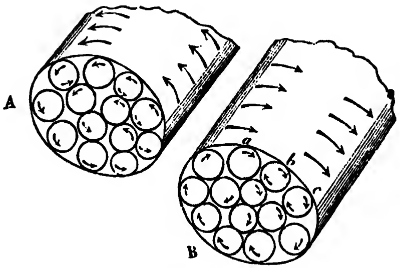

Fig. 376.

The resultant of the actions of all the molecular currents is equivalent to that of a single current, which traverses the outside of a magnet. For by inspection of fig. 376, in which the molecular currents are represented by a series of small internal circles in the two ends of a cylindrical bar, it will be seen that the adjacent parts of the currents oppose one another, and cannot exercise any external electrodynamic action, which is not the case with those on the surface.

The direction of these currents in magnets can be ascertained by considering the suspended solenoid. If we suppose it traversed by a current, and in equilibrium in the magnetic meridian, it will set in such a position that in the lower half of each coil the current flows from *east to west.* We may then establish the following rule. *At the north pole (English) of a magnet the direction of the Ampèrian currents is opposite that of the hands of a watch, and at the south pole the direction is the same as that of the hands.*

466. **Terrestrial current.**—In order to explain on this supposition terrestrial magnetic effects, the existence of electrical currents is assumed which continually circulate round our globe from east to west, perpendicular to the magnetic meridian.

The resultant of their action is a single current traversing the

magnetic equator from east to west. These currents are supposed to be thermo-electric currents due to the variations of temperature caused by the successive influence of the sun on the different parts of the globe from east to west.

These currents direct magnetic needles; for a suspended magnetic needle comes to rest when the molecular currents on its under surface are parallel, and in the same direction as the earth currents. As the molecular currents are at right angles to the direction of its length, the needle places its greatest length at right angles to east and west, or north and south. Natural magnetisation is probably imparted in the same way to iron minerals.

CHAPTER XI.

ELECTROMAGNETS. TELEGRAPHS AND ELECTROMAGNETIC MOTORS.

467. **Electromagnets.**—*Electromagnets* are bars of soft iron which, under the influence of a voltaic current, become magnets; but this magnetism is only temporary, for the coercive force of perfectly soft iron is null, and the magnetism ceases as soon as the current ceases to pass through the wire. If, however, the iron is not quite pure, it retains more or less traces of magnetism. The electromagnets have the horse-shoe form, as shown in fig. 377, and a copper wire, covered with silk or cotton, is rolled several times round them on the two branches, so as to form two bobbins, A and B. In order that the two ends of the horse-shoe may be of opposite polarity the winding on the two limbs, A and B, must be such that, if the horse-shoe were straightened out, it would be in the same direction.

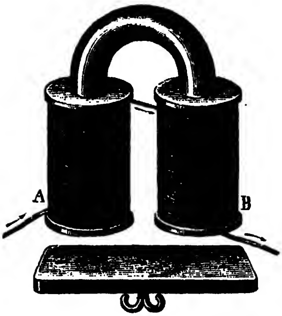

Fig. 377.

Electromagnets, instead of being made in one piece, are frequently constructed of two cylinders, firmly screwed to a stout piece of the same metal. Such are the electromagnets in Morse's

telegraph (472), the electromagnetic machine (477). The helices on them must be such that the current shall flow in the same direction as the hands of a watch as seen from the south pole, and against the hands of a watch as seen from the north pole.

The force of such magnets depends on their dimensions, on the number of turns of wire, and on the strength of the current. An electromagnet need not be very powerful to support one person

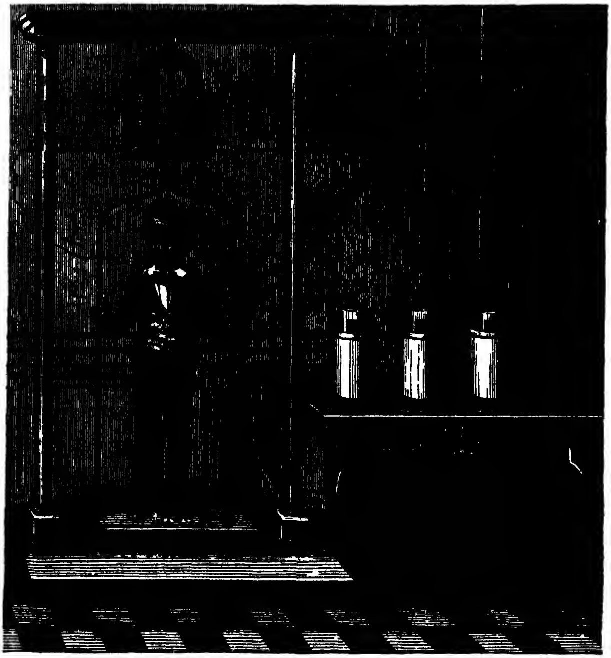

Fig. 378.

(fig. 378). Electromagnets have had extended applications, in telegraphs, in clocks, and in electromagnetic engines.

ELECTRIC TELEGRAPH.

468. **Electric telegraphs.**—These are apparatus by which signals can be transmitted to considerable distances, and with

enormous velocity, by means of voltaic currents propagated in metallic wires. Towards the end of the last century, and at the beginning of the present, many philosophers proposed to correspond at a distance by means of the effects produced by electrical machines when propagated in insulated conducting wires. In 1811, Sœmmering invented a telegraph in which he used the decomposition of water for giving signals. In 1820, at a time when the electromagnet was unknown, Ampère proposed to correspond by means of magnetic needles, above which a current was sent, as many wires and needles being used as letters were required. In 1834, Gauss and Weber constructed an electromagnetic telegraph, in which a voltaic current transmitted by a wire acted on a magnetised bar; the oscillations of which under its influence were observed by a telescope. They succeeded in thus sending signals from the Observatory to the Physical Cabinet in Göttingen, a distance of a mile and a quarter, and to them belongs the honour of having first demonstrated experimentally the possibility of electrical communication at a considerable distance. In 1837, Steinheil in Munich, and Wheatstone in London, constructed telegraphs in which several wires each acted on a single needle: the current in the first case being produced by an electromagnetic machine, and in the second by a constant battery.

Every electric telegraph consists essentially of three parts: 1, a *circuit*, consisting of a metallic connection between two places, and an *electromotor*, for producing the current; 2, a *communicator*, for sending the signals from the one station; and, 3, an *indicator*, for receiving them at the other station. The manner in which these objects, especially the last two, are effected can be greatly varied; the three principal systems are the needle telegraph, the dial telegraph, and the printing telegraph.

The needle telegraph is essentially a vertical galvanometer; that is to say, a magnetic needle suspended vertically in a coil of insulated wire. To the needle is attached an index, which is seen on the front of the apparatus. The signs are made by transmitting the current in different directions through the multiplier, by which the needle is deflected either to the right or left, according to the will of the operator. The instrument by which this is effected is called a key, or *commutator*.

In the *dial* telegraph an electromagnet causes an index to move over a dial provided with the twenty-six letters of the alphabet; that letter in front of which the needle stops, being the letter sent.

This kind of telegraph does not send the message with great rapidity; yet, as the manipulation is very simple, it is frequently used on railways.

Morse's telegraph will be described in the following paragraph :

469. **Principle of Morse's telegraph.**—This telegraph is based *on the temporary magnetisation of an electromagnet by the intermittent passage of currents.* Thus let E (fig. 379) be a fixed electromagnet, the insulated wires of which are attached to the two binding screws, *a* and *b*. Above this magnet is a lever, *mn*, movable about an axis, *i*, and ending in an armature of soft iron, *m*, so that, whenever the magnet is traversed by a current, the armature is attracted, and the part of the lever on the right of the fulcrum is lowered; then, when the current no longer passes, a spring, R, raises the lever to an extent regulated by a screw, O.

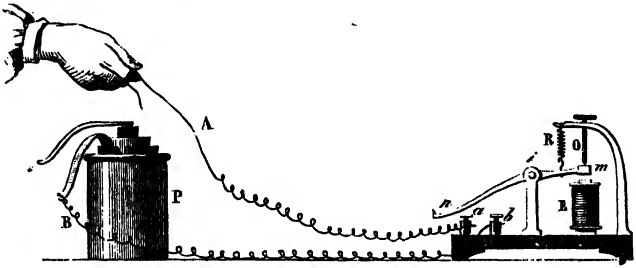

Fig. 379.

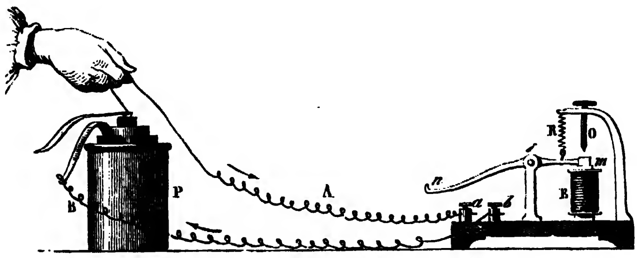

Fig. 380.

Suppose, for example, the electromagnet is at Bristol, and that there is a battery, P, at London, and two metal wires, A and B, by one of which the binding screw, *b*, is permanently connected with

the negative pole of the battery, while the experimenter holds the other wire in his hand. So long as the experimenter does not place the wire which he holds in his hand in contact with the positive pole, the current does not pass ; and, as the electromagnet does not act, the arm of the lever is raised (fig. 379). But the moment contact is made, the current is closed, the electromagnet attracts, and the lever is lowered (fig. 380) ; but it resumes its original position as soon as contact is broken, and so on at the will of the operator. Thus one person at London can cause the lever, *mn*, to oscillate at Bristol as often and as rapidly as possible as he desires. This is, in its simplest expression, the elementary mechanism of electrical telegraphs based on electromagnetism. It only remains to give to these oscillations a definite meaning.

470. **Line wire.**—Of the various essentials for a telegraphic communication, the batteries or sources of power have been already described, and we shall therefore pass to the explanation of the *circuit*, or *line wire.*

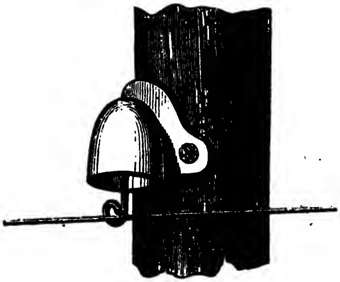

Fig. 381.

Line wires are either *aerial*, *subterranean*, or *submarine*.

The aerial wire consists of a stout galvanised iron wire connecting two stations. At certain intervals are wooden posts, to which are attached insulating supports of porcelain, which sustain the wire (fig. 381). The subterranean wires are used for cases in which an aerial wire would not be sufficiently protected against accident, as in the towns. They consist usually of copper wires covered with gutta percha ; this insulates them from the earth in which they are placed.

Submarine wires or cables are such as are employed in deep seas where great strength is required. The ordinary form is represented in figs. 382 and 383. The *core* consists of seven fine wires of very pure copper, which are twisted together and surrounded by an insulating covering. This is surrounded by an insulating coating of four concentric layers of gutta percha alternating with the same number of layers of a material known as *Chatterton's compound*, which is essentially a mixture of resin, pitch, and gutta percha applied hot.

Round this is a layer of tarred hemp, and this again is surrounded by a protective coating of steel wire coated with tarred hemp, which preserve it from the corrosive action of the sea.

Fig. 382 gives a longitudinal view of a submarine cable, and

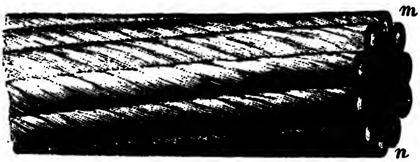

Fig. 382.

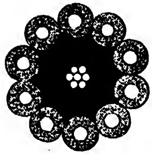

Fig. 383.

fig. 383 a cross section. The diameter of the cable is about an inch, and it weighs about a ton to the mile.

471. **The earth as a conductor.** In figs. 379 and 380 we have not merely a wire connecting the positive pole of the battery with the electromagnet, but there is a second one which acts on a return wire. In 1837 Steinheil made the very important discovery that the earth might be utilised for the return conductor. This has the twofold advantage of doing away with the expense of a second wire, and also of lessening the resistance.

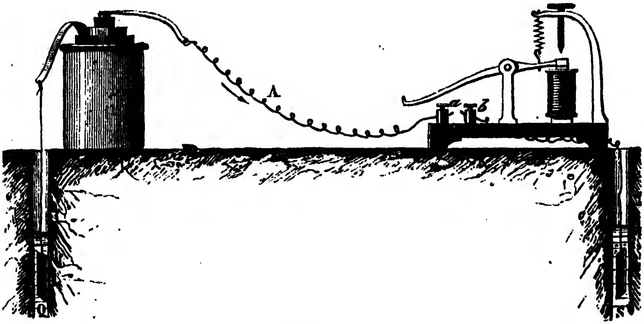

Fig. 384.

With this view, at the sending station, a long copper wire is attached to the negative pole, which is fixed at the other end to a copper plate, Q. This plate is placed in water if possible (fig. 384), or at all events is sunk some depth in earth. In like manner, at the

receiving station, a similar wire and plate are connected with the binding screw, *b*. Thus while the negative electricity passes into the ground by the plate, Q, the positive electricity which reaches the electromagnet and the binding screw, enters the ground by the plate, S. Hence there is in the wire, A, and in the electromagnet, the same circulation, and therefore the same effects as when the binding screw, *b*, communicates directly with the negative pole of the battery by means of a metal wire.

472. **Morse's telegraph.**—Fig. 385 represents a post at which a dispatch is being sent by the help of this apparatus, and fig. 386

Fig. 385.

represents the receiving station. At each post the apparatus is the same; it is double, and consists of two distinct parts, the ***key***, by which the signals are sent, and the ***receiving instrument*** which

registers them. These two parts are represented on a larger scale in figs. 387 and 388.

To understand how they work let us commence with fig. 385. Below the table is a box containing the battery, which furnishes the current. This passes by the wire, P, into the key, which will be afterwards described. Thence it passes into a small galvanometer,

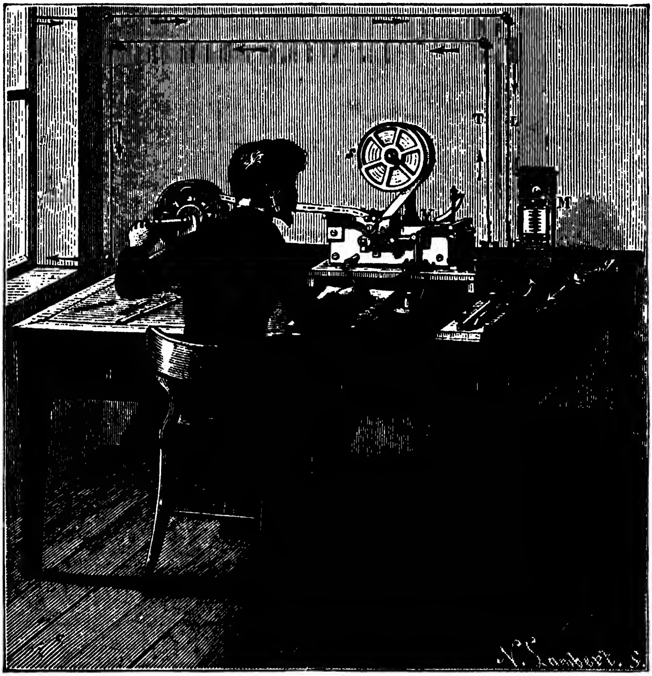

Fig. 386.

g, which indicates by the deflection of its needle whether the current is transmitted or not. The current ultimately attains the piece, M, which acts as a lightning conductor, as we shall afterwards see, and thence it goes to the wire, L, which is the *line wire.*

This wire is again seen at the top of fig. 386, whence the arriving current again passes into the lightning conductor, then into a galvanometer, and next a key, whence it passes into the electromag-

net, which makes part of the receiver. It then enters the wire, T, which leads it to earth.

473. **Morse's key and receiving instrument.**—The general arrangement of the apparatus being understood, the following are the details of its action. The *key* consists of a small mahogany base, which acts as support for a metallic lever, *hk* (fig. 387), movable in its middle on a horizontal axis. The extremity, B, of this lever is always pressed upwards by a spring, *r*, beneath; at the other

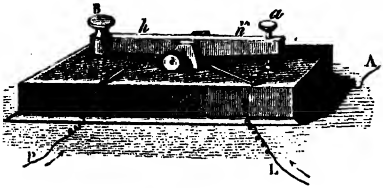

Fig. 387.

end a screw passes through it, which rests on a small metal support in contact with the wire, A. Fig. 387 represents the key at the moment it receives the dispatch, as t works for instance in fig. 386. The current enters then by the wire, L, which is the line wire, rises into the lever, *kh*, and descends by the screw pin, *a*, into the wire, A, which leads to the indicator. If, on the other hand, the key is to be used for sending a message, as represented in fig. 385, it will be seen that the lever, *kh*, does not touch the metal pin in which the wire, P, terminates. But if the lever, *h*, is lowered by pressing the end, B, contact is set up; and the current, P, at once passes into the lever, *hk*, and thence into the wire, L, which leads it to the post signalled to; for the same wire is used to send and to receive the message.

The *indicator* consists of an electromagnet, E, which whenever

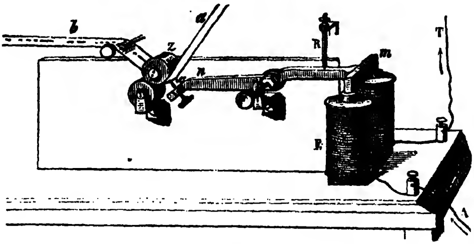

Fig. 388.

the current is transmitted, acts attractively on an armature of soft iron, *m*, fixed at the end of a lever. *mn*, movable about an axis, *x*; when the current is open, the lever is raised by a spring, R. At

the other end of the lever there is a pencil, x, which writes the signals. For this purpose a long band of strong paper, *ab*, rolled round a drum, S (figs. 385 and 386), passes between two copper rollers with a rough surface, turning in contrary directions. Drawn in the direction of the arrows, the band of paper becomes rolled on a second drum, Q, which is turned by hand. A clockwork motion placed in the box, V, works the rollers, between which the band of paper passes.

The paper being thus set in motion, whenever the electromagnet works, the point, x, strikes the paper, and, without perforating it, produces an indentation, the shape of which depends on the time during which the point is in contact with the paper. If it only strikes it instantaneously, it makes a dot (.) ; but if the contact has any duration a line of corresponding length is produced. Hence, by varying the length of contact of the transmitting key at one station, a combination of dots or points may be produced at another station, and it is only necessary to give a definite meaning to these combinations.

This is effected as follows in Morse's alphabet:

	PRINTING.	SINGLE NEEDLE.		PRINTING.	SINGLE NEEDLE.
A	- —	\/	**N**	— -	/\
B	— - - -	/\\\	**O**	— — —	///
C	— - — -	/\/\	**P**	- — — -	\//\
D	— - -	/\\	**Q**	— — - —	//\/
E	-	\	**R**	- — -	\/\
F	- - — -	\\/\	**S**	- - -	\\\
G	— — -	//\	**T**	—	/
H	- - - -	\\\\	**U**	- - —	\\/
I	- -	\\	**V**	- - - —	\\\/
J	- — — —	\///	**W**	- — —	\//
K	— - —	/\/	**X**	— - - —	/\\/
L	- — - -	\/\\	**Y**	— - — —	/\//
M	— —	//	**Z**	— — - -	//\\

Fig. 389.

Any one present while a message is being received at a telegraph station, is astonished at the promptitude and accuracy with which signals are read and transmitted by the operators. These acquire such skill that they can read a message by the sounds which the armature makes in striking against the electromagnet of the indicator.

474. **Improvements in Morse's telegraph.**—In the apparatus just described, the indentations on the paper only give indistinct dots and dashes, unless the current transmitted be very powerful. To get rid of this inconvenience, and to expend less force, the apparatus has been modified so that the signals can be traced in ink. With this view, all the other parts being the same, the following arrangement is made :

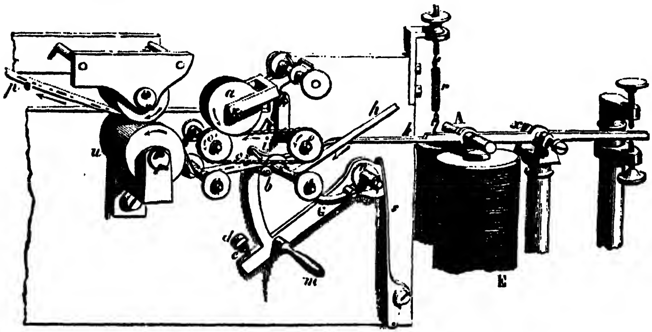

Fig. 390.

A roller, *a*, covered with flannel, is moistened with a suitable ink. Above the roller, and in contact with it, is an endless band rolled on two pulleys, *o*, *o′*, which are turned by the clockwork motion which moves the paper. This is kept within a roller, *b*, very near the chain, but not touching it. That being premised, whenever the current passes in the electromagnet, the armature, A, is attracted, the arm of the lever, *k*, is depressed, and a pin, *i*, at its end rests on the band, and places it in contact with the paper. The band depositing the ink which it has taken from the roller, makes on the paper as it moves along, a dot or a dash, according to the length of time the current passes, and which dots and dashes have the same meaning as above.

475. **Lightning conductor.**—Besides the parts of the telegraph

already described there are three of which mention must be made; the lightning conductor, the alarum, and the relay.

The influence of storm clouds in decomposing the natural electricity of the wire, often produces sufficient tension, not merely to interfere with the transmission of the despatches, but also to produce dangerous discharges. The lightning conductor is designed to remedy these inconveniences.

Represented at M in figs. 385 and 386, it consists of a vertical stand on which are two copper plates, indented like a saw, and arranged so that the teeth are near each other but do not touch. One of these plates is connected with the earth, the other with the line wire. Hence, when, by the inductive action of a storm cloud, electricity accumulates in wires and in the apparatus, it escapes by the points to the plate which is connected with the ground, and thus all danger from a discharge is avoided.

476. **Electrical alarum.**—The electrical alarum is intended to warn the receiving station that a despatch is about to be sent. Represented in fig. 391, it consists of a board on which is fixed an electromagnet by means of a piece of brass, E. The current from the line arriving by a binding screw, *m*, passes to the wire of the electromagnet, thence into the armature, *a*, into a steel spring, *c*, which presses against the armature, and ultimately emerges by a second terminal, *n*.

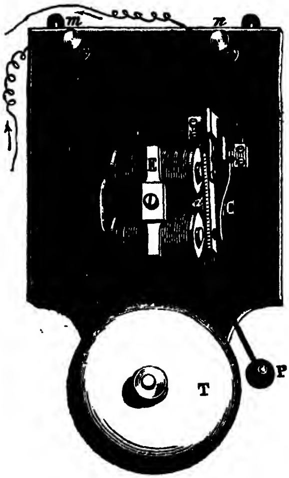

Fig. 391.

Thus, whenever the current of the line wire reaches the electromagnet, the armature, *a*, is attracted, and a clapper, P, fixed to this armature, strikes against a bell, T, and makes it sound. The moment the clapper strikes, as the armature is no longer in contact with the spring, C, the current is open, the electromagnet no longer attracts, and the armature reverts to its original position by the action of a spring, *e*, to which it is fixed. The current being closed afresh, a second attraction takes place,

and so on until the telegraph clerk, thus warned, lets the current pass directly into the indicator without passing through the alarum. This he accomplishes by means of an instrument called the *shunt.*

Relay. In describing the receiver we have assumed that the current of the line coming by the wire, C (fig. 392), entered directly into the electromagnet, and worked the armature, A, producing a despatch; but when the current has to traverse a distance of a few miles, owing to the resistance of the wire and the losses of insulation, its intensity is diminished so greatly that it cannot act upon the electromagnet with sufficient force to print a despatch. Hence it is necessary to have recourse to a relay, that is, to an auxiliary electromagnet, which is still traversed by the current of the line, but which serves to introduce into the communicator the current of a *local battery* of four or five elements placed at the station, and only used to print the signals transmitted by the wire.

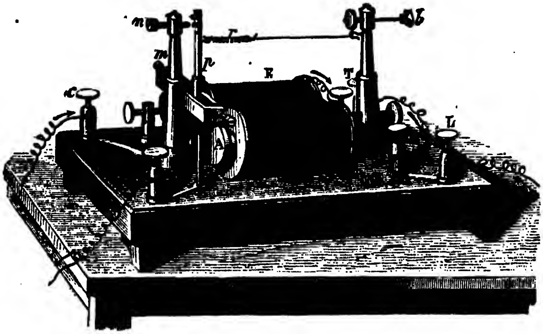

Fig. 392.

For this purpose the current from the line entering the relay by the binding screw, L (fig. 392), passes into an electromagnet, E, whence it passes into the earth by the binding screw, T. Now, each time that the current of the line passes into the relay, the electromagnet attracts an armature, A, fixed at the bottom of a vertical lever, *p*, which oscillates about a horizontal axis.

At each oscillation the top of the lever, *p*, strikes against a button, *n*, and at this moment the current of the local battery which enters by the binding screw, *c*, ascends the column, *m*, passes into the lever, *p*, descends by the rod, *o*, which transmits it to the binding screw, T: thence it enters the electromagnet of the indicator, whence

it emerges by the wire, Z, to return to the local battery from which it started. Then when the current of the line is open, the electromagnet of the relay does not act, and the lever, *p*, drawn by a spring, *r*, leaves the button, *n*, as shown in the drawing, and the local current no longer passes. Thus the relay transmits to the indicator exactly the same phases of passage and intermittence as those effected by the key in the station which sends the despatch.

477. **Electromagnetic machines.**—Many physicists have attempted to utilise the attractive force of electromagnets as a motive power. M. Jacobi, of St. Petersburg, appears to have been the first to construct a machine of this kind, with which, in 1838, he moved on the Neva a small boat containing twelve persons. Since that time the construction of these machines has been materially modified; but in all the expense of zinc and acids which they use far exceeds that of steam engines of the same force. Until some cheaper source of electricity shall have been discovered there is no expectation that they can be applied at all advantageously.

Fig. 393 represents an electromagnetic machine constructed by Froment. It consists of four electromagnets acting in two couples, on two pieces of soft iron, P, only one of which is seen in the drawing. This piece, attracted by the electromagnets, EF, transmits the motion by means of a connecting rod to a crank fixed at the end of a horizontal axis. To this is fixed a fly-wheel like that of a steam engine, which is intended to regulate the rotatory motion. On this axis also is a piece of metal, *n*, of a greater diameter, the action of which will be described presently.

The current of the battery, entering at A, passes into a cast-iron base, B, then by various metallic connections it reaches the metal piece, *n*. Thence the current ought to pass alternately to the first couple of electromagnets, EF, and then to the second, *ef*. In order to understand how this attraction in the path of the current is effected, let us refer to fig. 394 on the right of the picture, which represents a section of the piece, *n*, and its accessories. On this piece is a projection, *e*, which is called a *cam*, and which, during a complete turn, successively touches two springs, *a* and *b*; these are intended to transmit to the electromagnets the current, the direction of which is indicated by the unbarbed arrows; the barbed arrows do not show the direction of the current but the direction of the motion of the various pieces of the machine.

These details being known, it will be seen that the current passes

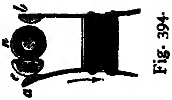

Fig. 394.

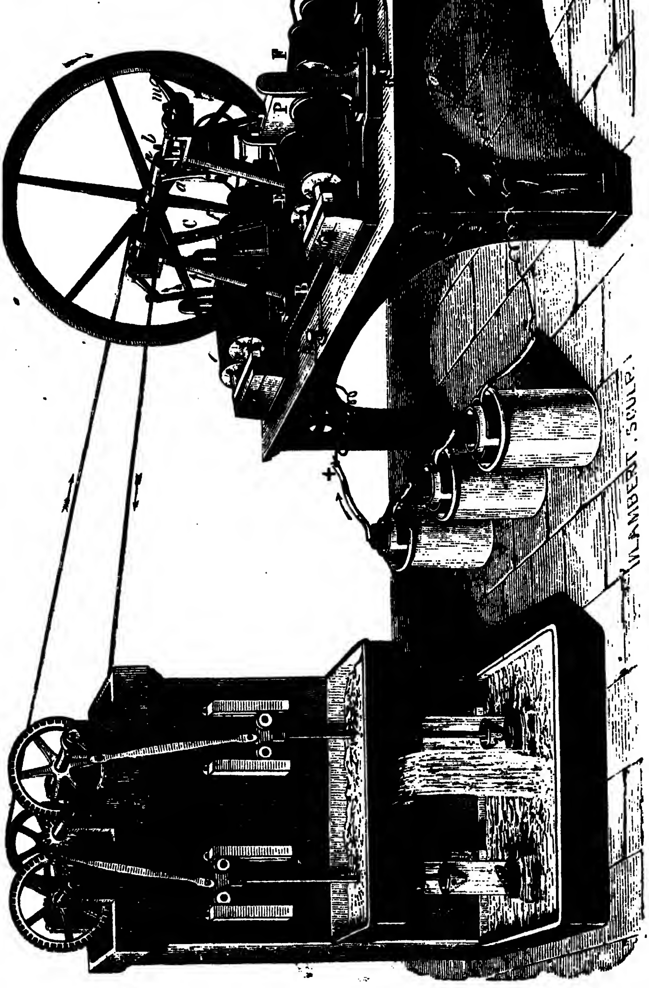

Fig. 393.

alternately into the two springs, *a* and *b*, and from thence into the two systems of electromagnets, EF and *ef*: the piece P is first of all attracted, then a similar one, which is placed at the other end of the axis of the fly-wheel. There is thus produced a continuous circulating motion, which is transmitted by an endless band to a system of wheel work, which works two lifting pumps.

CHAPTER XII.

INDUCTION BY CURRENTS.

478. **Induction by currents.**—We have already seen (398) that by the term *induction* is meant the action which electrified bodies exert at a distance on bodies in the natural state. Hitherto we have only had to deal with electrostatical induction; we shall now see that dynamical electricity produces analogous effects.

Faraday discovered this class of phenomena in 1832, and he gave the name of *currents of induction*, or *induced currents*, to instantaneous currents developed in metallic conductors under the influence of metallic conductors traversed by electric currents, or by the

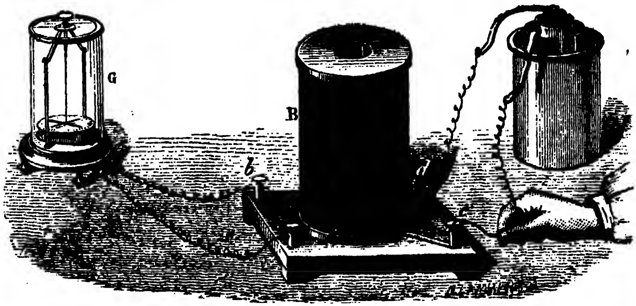

Fig. 395.

influence of powerful magnets, or even by the magnetic action of the earth; and the currents which give rise to them he has called *inducing currents*.

The inductive action of currents at the moment of opening or closing may be shown by means of a bobbin with two wires. This

consists (fig. 394) of a cylinder of wood or of cardboard, on which a quantity of stout silk-covered copper wire is coiled; on this is coiled a considerably greater length of fine copper wire, also insulated by being covered with silk. This latter coil, which is called the *secondary coil*, is connected by its ends with two binding screws, *a*, *b*, from which wires pass to a galvanometer, while the thicker wire, the *primary coil*, is connected by its extremities with two binding screws, *c* and *d*. One of these, *d*, being connected with one pole of a battery, when a wire from the other pole is connected with *c*, the current passes in the primary coil, and in this alone. The following phenomena are then observed:

i. At the moment at which the thick wire is traversed by the current the galvanometer, by the deflection of the needle, indicates the existence in the *secondary coil* of a current *inverse* to that in the primary coil, that is, in the contrary direction; this is only instantaneous, for the needle immediately reverts to zero, and remains so as long as the inducing current passes through *cd*.

ii. At the moment at which the current is opened, that is, when the wire, *cd*, ceases to be traversed by a current, there is again produced in the wire, *ab*, an induced current instantaneous like the first, but *direct*, that is, in the same direction as the inducing current.

479. **Induction by magnets and by the action of the earth.**—It has been seen that the influence of a current magnetises a steel bar; in like manner a magnet can produce induced electrical currents in metallic circuits. Faraday has shown this by means of a coil with a single wire of 200 to 300 yards in length. The two extremities of the wire being connected with the galvanometer, as shown in fig. 395, a strongly magnetised bar is suddenly inserted in the bobbin, and the following phenomena are observed:

i. At the moment at which the magnet is introduced, the galvanometer indicates in the wire the existence of a current, the direction of which is opposed to that which circulates round the magnet, considering the latter as a solenoid on Ampère's theory (465).

ii. The needle soon returns to zero, and remains there as long as the magnet is in the coil; when it is withdrawn, the needle of the galvanometer, which has returned to zero, indicates the existence of a direct current.

The inductive action of magnets may also be illustrated by the following experiment: a bar of soft iron is placed in the above bobbin and a strong magnet suddenly brought in contact with it;

the needle of the galvanometer is deflected, but returns to zero when the magnet is stationary, and is deflected in the opposite direction when it is removed. The induction is here produced by the magnetisation of the soft iron bar in the interior of the bobbin under the influence of the magnet.

Faraday discovered that terrestrial magnetism can develop induced currents in metallic bodies in motion; that it acts like a powerful magnet placed in the interior of the earth in the direction of the dipping needle, or, according to the theory of Ampère, like a

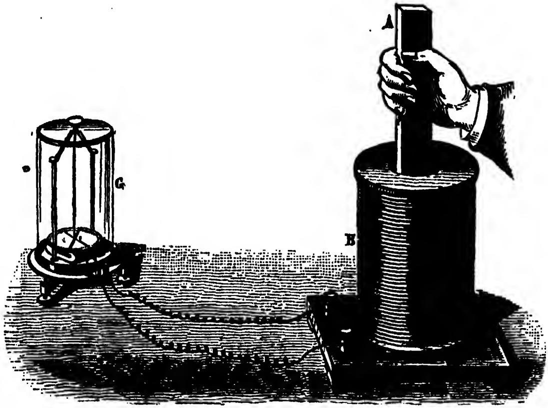

Fig. 390.

series of electrical currents directed from east to west parallel to the magnetic equator. He first proved this by placing a long helix of copper wire covered with silk in the plane of the magnetic meridian parallel to the dipping needle; by turning this helix through a semicircle round an axis, in its middle, perpendicular to its length, he observed that at each turn a galvanometer connected with the two ends of the helix was deflected.

480. **Properties of induced currents.**—Notwithstanding their instantaneous character, it appears mainly from the experiments of Faraday their discoverer, that induced currents have all the properties of ordinary currents. They produce violent physiological luminous, calorific, and chemical effects, and finally give rise to new induced currents. They also deflect the magnetic needle, and

magnetise steel bars when they are passed through a copper wire coiled in a helix round the bars.

The intensity of the shock produced by induced currents renders their effects comparable to those of electricity in a state of tension. But as they act on the galvanometer the electricity is present, both in a state of tension and in the dynamical condition.

These phenomena of induction currents are well seen in Ruhmkorff's coil, which we shall now describe.

481. **Ruhmkorff's coil.**—This is an arrangement for producing induced currents, in which a current is induced by the action of an electric current, whose circuit is alternately opened and closed in rapid succession. These instruments, known as *inductoriums*, or *induction coils*, present considerable variety in their construction, but all consist essentially of a hollow cylinder in which is a bar of soft iron, or bundle of iron wires, with two helices coiled round it, one connected with the poles of a battery, the current of which is alternately opened and closed by a self-acting arrangement, and the other serving for the development of the induced current. By means of these apparatus, with a current of three or four Grove's cells, physical, chemical, and physiological effects are produced equal to and superior to those obtainable with electrical machines and even the most powerful Leyden batteries.

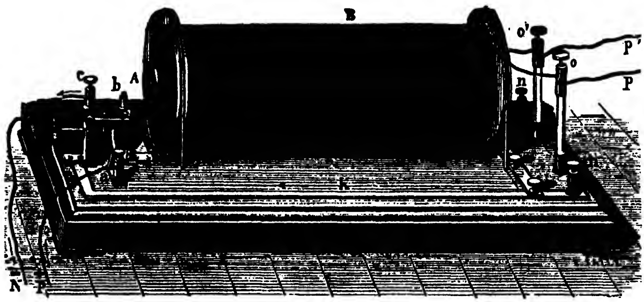

Fig. 397.

Of all the forms those constructed by Ruhmkorff in Paris, and by Ladd and Apps in this country, are the most powerful. Fig. 396 is a representation of one, the coil of which is about 14 inches in length. The *primary* or *inducing* wire is of copper, and is about 2 mm in diameter, and 4 or 5 yards in length. It is coiled directly

on a cylinder of cardboard, which forms the nucleus of the apparatus, and is enclosed in an insulating cylinder of glass, or of caoutchouc. On these is coiled the secondary or induced wire, which is also of copper, and is about $\frac{1}{3}$mm. in diameter. A great point in these apparatus is the insulation. The wires are not merely insulated by being in the first case covered with silk, but each individual coil is separated from the rest by a layer of melted shellac. The length of the secondary wire varies greatly; in some of the largest sizes it is as much as 60 miles. With these great lengths the wire is thinner, about $\frac{1}{6}$mm.

The following is the working of the apparatus. The current arriving by the wire, P, at a binding screw, *a*, passes thence into the commutator, C (fig. 398); thence by the binding screw, *b*, it enters the primary wire, where it acts inductively on the secondary wire; having traversed the primary wire it emerges by the wire, *s*. Following the direction of the arrows, it will be seen that the current ascends in the binding screw, *i*, reaches an oscillating piece of iron, *o*, called the *hammer*, descends by the *anvil*, *h*, and passes into a copper plate, K, which takes it to the commutator, C. It goes from there to the binding screw, *c*, and finally to the negative pole of the battery by the wire, N.

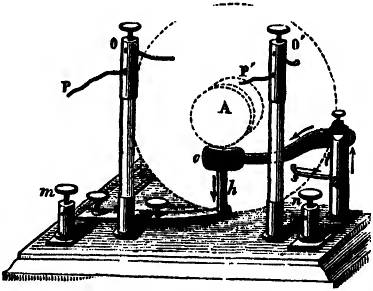

Fig. 398.

The current in the primary wire only acts inductively on the secondary wire (478), when it opens or closes, and hence it must be constantly interrupted. This is effected by means of the oscillating hammer, *o*, omitted in figure 397, but represented on a larger scale in fig. 398. In the centre of the bobbin is a bundle of soft iron wires, forming together a cylinder a little larger than the bobbin, and thus projecting at the end as seen at A. When the current passes in the primary wire, this hammer, *o*, is attracted; but immediately, there being no contact between *o* and *h*, the current is broken, the magnetisation ceases, and the hammer falls; the current again passing, the same series of phenomena recommences, so that the hammer oscillates with great rapidity.

In proportion as the current passes thus intermittently in the primary wire of the bobbin, at each interruption an induced current, alternately direct and inverse, is produced in the secondary wire. But as this is perfectly insulated, the current acquires such an intensity as to produce very powerful effects. Fizeau has increased this intensity by interposing a condenser in the induced circuit. As constructed by Ruhmkorff, for his largest apparatus, this consists of 150 sheets of tinfoil about 18 inches square; these sheets being joined are coiled on two sides of a sheet of oiled silk, which insulates them, forming thus two armatures; they are then coiled several times round each other, so that the whole can be placed below the helix in the base of the apparatus. One of these armatures, the positive, is connected with the binding screw, *i*, which receives the current on emerging from the bobbin; and the other, the negative, is connected with the binding screw, *m*, which communicates by the plate, K, with the commutator, C, and with the battery.

482. **Effects produced by Ruhmkorff's coil.**—The high degree of tension which the electricity of induction coil machines possesses has long been known, and many luminous and calorific effects have been obtained by their means. But it is only since the improvements which Ruhmkorff has introduced into his coil, that it has been possible to utilise all the tension of induced currents, and to show that these currents possess the properties of statical as well as dynamical electricity.

Induced currents are produced in the coil at each opening and breaking of contact. But these currents are not equal either in duration or in tension. The direct current, or that on *opening*, is of shorter duration, but more tension; that of *closing* of longer duration but less tension. Hence if the two ends P, and P′, of the fine wire (figs. 397 and 398) are connected, as there are two equal and contrary quantities of electricity in the wire the two currents neutralise each other. If a galvanometer is placed in the circuit, only a very feeble deflection is produced in the direction of the direct current. This is not the case if the two extremities, P and P′, of the wire are separated. As the resistance of the air is then opposed to the passage of the currents, that which has most tension, that is, the direct one, passes in excess, and the more so the greater the distance of P and P′ up to a certain limit at which neither pass. There are then at P and P′ nothing but tensions alternately in contrary directions.

The effects of the coil, like those of the battery, may be classed

under the heads *physiological*, *chemical*, *calorific*, *luminous*, *mechanical*; they have this difference, that they are enormously more intense.

The *physiological* effects of Ruhmkorff's coil are very powerful; in fact, the shocks are so violent that many experimenters have been suddenly prostrated by them. A rabbit may be killed with an induction current arising from two of Bunsen's elements, and a somewhat larger number of couples would kill a man.

The *calorific* effects are also easily observed; it is simply necessary to interpose a very fine iron wire between the two ends, P and P′, of the induced wire; this iron wire is immediately melted, and burns with a bright light. The spark of the Ruhmkorff's coil is used to fire mines in military and mining operations.

The *chemical* effects are very varied, inasmuch as the apparatus produces both dynamical electricity and electricity in a high state of tension. Thus, according to the shape and distance of the platinum electrodes immersed in water, and to the degree of acidulation of the water, either luminous effects may be produced in water without decomposition, or the water may be decomposed and the mixed gases disengaged at the two poles, or the decomposition may take place, and the mixed gases separate either at a single pole or at both poles.

The *luminous* effects of Ruhmkorff's coil are also very remarkable, and vary according as they take place in air, in vacuo, or in very rarefied vapours. In air the coil produces a very bright loud spark, which, with the largest-sized coils, has a length of eighteen inches. In vacuo the effects are also remarkable. The experiment is made by connecting the two wires of the coil, P and P′, with the two rods of the electrical egg (fig. 328), used for producing in vacuo the luminous effects of the electrical machine. A vacuum having been produced, a beautiful luminous trail is produced from one knob to the other, which is virtually constant, and has the same intensity as that obtained with a powerful electrical machine when the plate is turned.

If this light be closely observed, it will be found that if some vapour of turpentine, or wood spirit, or bisulphide of carbon, have been introduced into the globe before exhaustion, instead of being continuous, the light consists of a series of alternately dark and bright zones, forming a pile of electric light between the two poles. This phenomenon is known as the *stratification of the*

electric light, and is due to the circumstance that the current is discontinuous.

The brilliancy and beauty of the stratification of the electric light are most remarkable when the discharge of the Ruhmkorff's coil takes place in glass tubes containing a highly rarefied vapour or gas. These phenomena, which have been investigated by Masson, Grove, Gassiot, Plücker, etc., are produced by means of sealed glass tubes first constructed by Geissler, of Bonn. These tubes are filled with different gases or vapours, and are then exhausted. At the ends of the tubes two platinum wires are soldered into the glass.

When the two platinum wires are connected with the ends of a

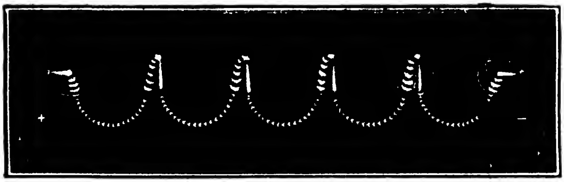

Fig. 399.

Ruhmkorff's coil, magnificent lustrous striæ, separated by dark bands, are produced all through the tube. These striæ vary in shape, colour, and lustre with the degree of the vacuum, the nature of the gas or vapour, and the dimensions of the tube. The phenomenon has occasionally a still more brilliant aspect from the fluorescence which the electric discharge excites in the glass.

Fig. 399 represents the striæ given by hydrogen; in the bulbs the light is white, in the capillary parts it is red.

In carbonic acid the colour is greenish, and the striæ have not the same shape as in hydrogen; in nitrogen the light is greenish yellow.

Mechanical effects. Ruhmkorff's coil also produces mechanical effects so powerful that, with the largest apparatus, glass plates two inches thick have been perforated. The result, however, is not obtained by a single charge, but by several successive charges.

The experiment is arranged as shown in fig. 400. The two poles of the induced current correspond to the binding screws, *a* and *b*; by means of a copper wire, the pole, *a*, is connected with the lower part of an apparatus for piercing glass like that already described

(fig. 346), the other pole is attached to the upper conductor by a wire, *d*. The latter is insulated in a large glass tube, *r*, filled with shellac, which is run in while in a state of fusion. Between the two conductors is the glass to be perforated, V. When this pre-

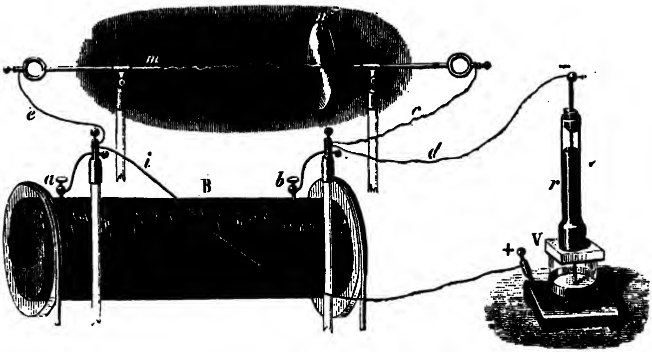

Fig. 400.

sents too great a resistance, there is danger lest the spark pass in the coil itself, perforating the insulating layer which separates the wire, and then the coil is destroyed. To avoid this, two wires, *e* and *c*, connect the poles of the coil with two metallic rods, whose distance from each other can be regulated. If then the spark cannot penetrate through the glass, it bursts across with a bright spark and a loud report, and the coil is not injured.

CHAPTER XIII.

THERMOELECTRIC CURRENTS.

483. **Thermoelectricity.**—In 1821, Professor Seebeck, in Berlin, found that by heating one of the junctions of a metallic circuit, consisting of two metals soldered together, an electric current was produced. This phenomenon may be shown by means of the apparatus represented in fig. 401, which consists of a plate of copper, *mn*, the ends of which are bent and soldered to a plate of bismuth, *op*. In the interior of the circuit is a magnetic needle

moving on a pivot. When the apparatus is placed in the magnetic meridian, and one of the solderings gently heated, as shown in the figure, the needle is deflected in a manner which indicates the passage of a current from *n* to *m*, that is, from the heated to the cool junction in the copper. If, instead of heating the junction, *n*

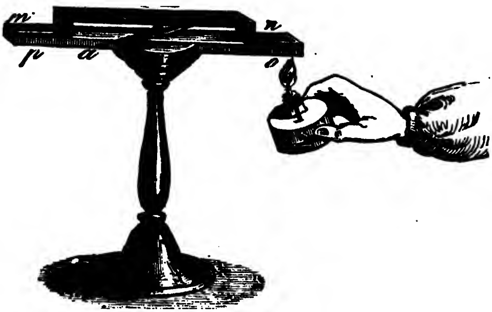

Fig. 401.

it is cooled by ice, or by placing upon it cotton wool moistened with ether, the other junction remaining at the ordinary temperature, a current is produced, but in the opposite direction; that is to say, from *m* to *n*. In both cases the current is more energetic in proportion as the *difference* in temperature of the solderings is greater.

Seebeck gives the name *thermoelectric* to this current, and the couple which produces it, to distinguish it from the *hydroelectric* or ordinary voltaic current and couple.

484. **Thermoelectric series.**—If small bars of two different metals are soldered together at one end while the free ends are connected with the wires of a galvanometer, and if now the point of junction of the two metals be heated, a current is produced, the direction of which is indicated by the deflection of the needle of the galvanometer. By experimenting in this way with different metals, they may be formed in a list such that each metal gives rise to positive electricity when associated with one of the following, and negative electricity with one of those that precede ; that is, that in heating the soldering, the positive current goes from the positive to the negative metal across the soldering, just as if the soldering represented the liquid in a hydroelectrical element ; hence out of

the element, in the connecting wire in the galvanometer for instance, the current goes from the negative to the positive metal. Thus a couple, bismuth-antimony, heated at the junction would correspond to a couple, zinc-copper, immersed in sulphuric acid.

Of all bodies, bismuth and selenium produce the greatest electromotive force ; but from the expense of this latter element, and on account of its low conducting power, antimony is generally substituted. The antimony is the negative metal but the positive pole, and the bismuth the positive metal but the negative pole, and the current goes from bismuth to antimony across the junction.

485. **Nobili's thermoelectric pile.**—Nobili devised a form of thermoelectric battery, or pile as it is usually termed, in which there are a large number of elements in a very small space. For this purpose he joined the couples of bismuth and antimony in such a manner, that after having formed a series of five couples, as represented in fig. 403, the bismuth from *b* was soldered to the antimony of a second series arranged similarly ; the last bismuth of this to the antimony of a third, and so on for four vertical series, containing together twenty couples, commencing by antimony, finishing by bismuth. Thus arranged, the couples are insulated from one another by means of small paper bands covered with varnish, and then enclosed in a copper frame, P (fig. 402), so that only the solderings appear at the two ends of the pile. Two small copper binding screws, *m* and *n*, insulated in an ivory ring, communicate in the interior, one with the first antimony, representing the positive pole and the other with the last bismuth, representing the negative pole. These binding screws communicate with the extremities of a galvanometer wire, when the thermoelectric current is to be observed.

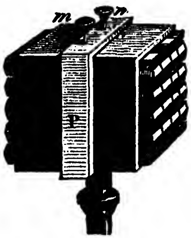

Fig. 402.

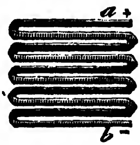

Fig. 403.

A Nobili's pile in combination with a galvanometer constitutes the most delicate and accurate means of measuring a temperature. Such an arrangement was first used by Melloni in his researches on the transmission of radiant heat. The arrangements he used is represented in figure 404.

On a wooden base, provided with levelling screws, a graduated copper rule, about a yard long, is fixed edgeways. On this rule the various parts composing the apparatus are placed, and their distances can be fixed by means of binding screws. *a* is a support for a Locatelli's lamp, or other source of heat; F and E are screens; C is a support for the bodies experimented on, and *m* is a thermo-

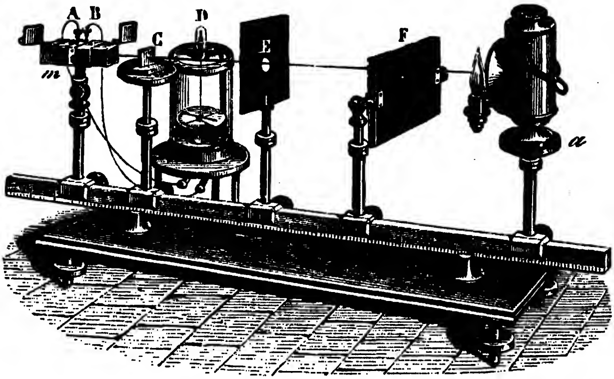

Fig. 404.

electrical battery. Near the apparatus is a galvanometer, D, which has only a comparatively few turns of a tolerably thick (1 mm.) copper wire. Such galvanometers are called *thermomultipliers.* The delicacy of this apparatus is so great that the heat of the hand is enough, at a distance of a yard from the pile, to deflect the needle of the galvanometer.

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